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PRELIMINARY EXAMINATION OF DETAILS RELATED TO A PROPOSED LONG SEA OUTFALL FOR THE IONA ISLAND SEWAGE TREATMENT PLANT

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1. INTRODUCTION

The Iona Island Sewage Treatment Plant Study Group was formed as a result of a condition imposed April 3, 1981 by Judge P. Govan in Provincial Court. The condition was part of a suspended sentence imposed on the Greater Vancouver Sewerage and Drainage District on four counts brought by the Province of British Columbia. The study group was to examine and recommend options available for improving the quality and location of the Iona discharge.

As part of the study group's consideration of options, the possibility that a long sea outfall might be put in place off Sturgeon Banks in the Strait of Georgia required that an assessment be carried out. While it was recognized that the development of a detailed design for a deep marine outfall would be complex, the need was nevertheless apparent for a fundamental understanding of the basis for a design and of the potential impact on the environment from such an installation. Any future decision to build such an outfall should recognize that many assumptions have been made in this assessment, and that a thorough engineering study of a long sea outfall is an essential prerequisite.

This report does not deal with possible effects on sediments or biota, but examines possible outfall configurations and the subsequent attenuation of effluent constituents in the water column.

The DKHPLM computer model was used to predict initial dilutions for various diffuser configurations at a depth of 65 metres. Using a design which achieved a realistic initial dilution in the order of 100:1, secondary dispersion effects were then manually computed to forecast effluent dilution at the shore under "worst-case" conditions.

Factors such as pumping requirements, bank stability, and other details of the diffuser design have not been incorporated into the assessment. However, the preliminary data generated should serve as a useful guide towards any final diffuser design.

2. THE MODEL

The DKHPLM computer model was developed by the U.S. Environmental Protection Agency (EPA). The program calculates the initial dilution and describes the zone of initial dilution around a discharge site. An EPA report which evaluated the model, described it as "reliable and well suited for evaluating impacts of municipal ocean discharges."[1] A recent paper which evaluated the DKHPLM and five other models indicated that predicted values had tended to be conservative for two actual field measurements[2]. No intensive testing of the model has been done to date in British Columbia.

The model takes into account the fact that wastewater discharged into the ocean has buoyancy and momentum. The wastewater forms a plume which rises and entrains ambient water, causing dilution of the wastewater in the plume. When the buoyancy and momentum reach equality with ambient conditions, the plume ceases to rise. If the plume does not reach the surface it is said to be trapped.

The DKHPLM model is specifically designed to examine multiport diffuser discharges to uniform or stratified environments under stagnant or flowing conditions. The following parameters are input variables into the program. They are discussed below:

2.1 Discharge Velocity: This variable depends upon the hydraulic head, the number of ports, and the diameter of the ports. The discharge velocity used was determined by calculating the rate of discharge through one port for a given situation and dividing by the area of the port. Although hydraulically this velocity is not strictly correct, it is sufficiently accurate for the purpose of this assessment.

Figure 1 illustrates how higher discharge velocities associated with fewer ports for wet weather flows reduce the initial dilution ratio. Thus, the discharge velocity is important in determining trapping height and initial dilution ratios.

2.2 Current Velocity: The faster the current velocity, the greater will be the initial dilution ratio and the lower the trapping height. This is evident when comparing curves for currents of 0.01 m/s and 0.0795 m/s in Figure 1.

This factor is significant in determining trapping height and initial dilution ratios.

2.3 Number of Ports: This is one factor in determining discharge velocity (See (2.1) above) and is therefore of similar importance.

2.4 Wastewater Temperature: The warmer the wastewater compared to the ambient temperature, the greater the initial dilution ratio tends to be. This is illustrated in Figure 2a.

This factor is of minor significance for the range of data applied.

2.5 Wastewater Salinity: A lower effluent salinity causes a slight increase in the initial dilution ratio for a fixed ambient salinity. This is illustrated in Figure 2b.

2.6 Ambient Salinity: The lower the ambient salinity , the lower the initial dilution ratio for a fixed wastewater salinity (Figure 2c). The effect on dilution is a change in dilution ratio of approximately 5:1 for every 1 ppt change in salinity. The ambient salinity at a depth of 65 metres would not be expected to vary significantly.

2.7 Ambient Temperature: The lower the ambient temperature compared to the wastewater temperature, the greater will be the initial dilution ratio (Figure 2d). However, the effect on dilution is minimal. This is consistent with (2.4) above.

2.8 Temperature Gradient: The larger the increase in ambient temperature per metre of depth above the outfall, the lower will be the trapping height and the initial dilution. Decreasing temperature gradients on the other hand increase the initial dilution (Figure 2e).

This factor can be significant in determining dilution ratios.

2.9 Salinity Gradient: The larger the decrease in ambient salinity per metre of rise above the outfall, the lower will be the initial dilution ratio and the trapping height (see Figure 2f).

This is a significant factor in the determination of initial dilution ratios.

2.10 Port Diameter: The smaller the port diameter, the larger the exit velocity (see 2.1 above). Figure 3 illustrates the effect of port diameter on the initial dilution ratios. Although it may be a critical consideration for hydraulic design, port diameter in the range from 0.1016 to 0.2032 metres (4 to 8 inches) has little effect on initial dilutions.

2.11 Port Spacing: The greater the spacing of ports, the greater is the amount of water available for dilution, hence the greater the dilution ratio. This is illustrated in Figure 1.

Port spacing is a significant factor in determining initial dilution ratios.

2.12 Angle of Port from Horizontal: This angle was varied from 0° to 90°. With the angle set at 0°, a lower level of trapping and a higher dilution ratio is obtained than at the 90° setting. The difference in dilution ratio is about 2 percent, and is therefore not significant (see Figure 2g).

2.13 Angle of Current to Plume: The EPA recommends that this angle range from 70° to 110°. Within this range the program makes no distinction but computes an effect equivalent to a common angle of 90°.

Although this factor is not considered significant within the recommended range, the initial dilution ratio is affected appreciably beyond the range of ±45° since a stagnant environment is then assumed. This situation produces considerably less dilution. These relationships are presented more fully in Section 4.4 and 4.5.

3. DATA BASE EXAMINED

3.1 AMBIENT CONDITIONS

Data on ambient conditions near the proposed location for the outfall had been collected by Tabata [3], Tabata and Strickland [4], and Tabata et al.[5] in the late 1960's. Temperature and current data were collected between April 16, 1969 and July 28, 1970 at a depth of 50 metres at station H-26 located off Sturgeon Bank. Cumulative percent frequency graphs for over 58 000 individual measurements of each of these parameters are included in Figures 4 and 5. Station H-26 was located 5.8 kilometres southwest of the Iona Island jetty and approximately 2.9 kilometres southwest of the assumed outfall location as shown in Figure 6.

To calculate salinity and temperature gradients, data were needed at different depths from the surface to the outfall depth. Salinity and temperature measurements were made at several depths at a nearby station, H-23N (Figure 6) between March 13 and March 15, 1968. Only 42 measurements were made at each depth. Gradients were calculated between the 50 and 10 metre depths, 50 and 20 metre depths, 50 and 30 metre depths, and 50 and 40 metre depths. Gradients were not calculated between the 50 metre depth and the surface, since the Fraser River severely influences data for the top 10 metres. Station H-23N was located approximately 7.2 kilometres southwest of the Iona Island jetty and 3.3 kilometres southwest of the assumed outfall location (see Figure 6). The gradient distributions are presented in Figures 7a and 7b for salinity and temperature respectively. Although data were not available between 50 metres and the assumed diffuser depth of 65 metres, fairly stable ambient conditions could be expected in this zone so that any deviations produced by this information gap should be tolerable.

3.2 EFFLUENT CONDITIONS

The Greater Vancouver Sewerage and Drainage District (GVS & DD) monitors influent and effluent quality at its sewage treatment plants on a regular basis. A summary of effluent quality is included in Table 2. Analyses

carried out on a monthly basis include metals, phosphorus, nitrogen, phenolics, sulphur compounds, oil and grease, M.B.A.S., cyanide, and TLM_{96}. More frequent analyses are performed for: BOD_5, once every 3 days; suspended solids, daily; and pH, dissolved oxygen, chlorine residual, and fecal coliform, two out of three days. The frequency of analysis depends upon the need for such analyses as well as limitations associated with any particular analysis.

4. DISCUSSION OF DIFFUSER DESIGN

An initial dilution ratio in the order of 100:1 was selected for design of the diffuser as it is a value recommended in several literature reviews. It is known that slicks will occur with initial dilution ratios below about 100:1[6]. The fundamental design target of 100:1 for initial dilution and the use of two outfall pipes [2.03 metre (80 inch) diameter] formed the basis for the computer design of the diffuser. Possible design options were examined for both "worst-case" and "average" conditions, with the former being applied in making a final selection. Although a "worst-case" situation would normally be very unlikely to occur (see Section 4.1), an initial ratio of about 100:1 would be beneficial for circumstances when optimum conditions did not prevail at the outfall. Such circumstances would include current directions relative to the diffuser which cause a lowering of the initial dilution ratio, upsets within the treatment plant which altered wastewater quality, and flow rate increases due to rainfall or to greater user loads. In addition a general safety factor for other circumstances not specifically noted is required.

4.1 "WORST-CASE" SITUATION

The ultimate "worst-case" conditions occur under a wet weather flow of 17.7 m^3/s (625 cfs). This produces the greatest flow through each port, and yields the lowest initial dilution ratio. Although such flows can occur at any time due to the fact that combined sewers serve most of the Iona Island sewerage area, flows of this magnitude are more likely to occur in the winter. For this reason, a representative sewage temperature of 12°C was chosen for the effluent, a temperature which is expected during winter and which would produce a lower initial dilution than would a higher temperature.

An ambient temperature of 7.95°C was chosen for the ocean. This was the 5th percentile temperature between March 25 and April 27, 1970. Figure 5 indicates that this value could occur from January to April and is therefore consistent with winter conditions. An ambient salinity of 29 parts per

thousand (ppt) was chosen for a discharge depth of 65 metres, based upon extrapolation of the linear salinity gradient from 50 to 40 metre depths to yield a salinity for the 65 metre depth. The angle of discharge from the horizontal and the discharge angle relative to the current were each assumed to be 90°. A 5th percentile low current velocity of 0.01 m/s was also used to reflect the "worst-case" conditions.

Since data were available to define both temperature and salinity gradients on a linear basis between the 50 metre depth and several lesser depths, an iterative process had to be undertaken so that the gradients chosen were applicable at the approximate depth at which trapping of the plume would occur. The range of salinity and temperature gradients used are indicated in Figure 7(a) and 7(b). This iterative process yielded a salinity gradient of -0.024 ppt/m, and a temperature gradient of 0.024°C/m for the "worst-case" situation. Trapping heights ranged from 35 metres to 40 metres below the water surface, depending upon port diameter and spacing. Temperature gradients of 0.024°C/m have been recorded during months when the ambient temperature was 7.95°C. Similarly, a salinity gradient of -0.024 ppt/m could occur at the same times.

Initial dilution ratios and trapping heights were calculated from the model for 180, 360, and 455 ports using 0.1016 metre (4 inch) diameter ports. Ports up to 0.2032 metre (8 inch) in diameter did not significantly alter the initial dilutions obtained. The use of 360 or 455 ports is in line with the number of ports used at existing long sea outfalls. The discharge rate in dry weather would be 0.013 m^3/s/port for 360 ports, increasing to 0.049 m^3/s/port under wet weather flow rates. The Clover Point outfall, off Victoria, is designed for a peak discharge of 0.017 m^3/s/port in 1981 and 0.039 m^3/s/port, ultimately[9]. This therefore suggests that as many as 455 ports could be considered for the Iona Island outfall to obtain the same discharge rate per port as provided at Clover Point.

To obtain an initial dilution ratio of 100:1, the model indicated that a spacing of 3.75 metres is required for 180 ports, a spacing of 2.5 metres

is required with 360 ports, and a spacing of 2.0 metres with 455 ports. The case of 360 ports at a 3 metre spacing was chosen, which yields an initial dilution ratio of about 110:1 and a trapping height of 33 metres above the ports. Comparable trapping heights were obtained for each of three cases where different numbers of ports were used (see Figure 1). The use of 180 ports would require 0.2032 metre diameter ports to avoid excessive velocities at high flows. However the area of ports to area of pipe factor for this case would be 0.90, which is outside the usual 0.33 to 0.67 range[7]. The use of 360 ports gave excellent correlation of design factors with values in Table 3 for the existing Honolulu (Sand Island) outfall. Data in Table 3 indicate that ranges exist in design factors for actual operating outfalls, therefore allowing other diffuser designs to be chosen which would also take further engineering considerations into account. This is illustrated for the case of 455 ports which would have a diffuser section of approximately the same length as for 360 ports and a 100:1 dilution, but which would produce different, yet valid, discharge rate per unit length (Q/L) and area of port to area of pipe factors (see Table 3).

It should be noted that a 100:1 initial dilution ratio will not be available when the angle of the current to the diffuser section is not within 45° of perpendicular. However, with proper alignment of the diffuser section, the occurrence of this type of situation can be minimized.

As well, information included in Alum et al. indicates that under certain situations, DKHPLM initial dilution ratios were between 50 and 90 percent of those actually measured in the field. Trapping heights were always found to be conservative, and were between 30 and 35 percent of those measured in the field[2].

4.2 AVERAGE SITUATION

Figure 1 indicates improved initial dilution ratios over "worst-case" when a mean fiftieth percentile (the mean of several fiftieth percentiles)

current of 0.0795 m/s was used for both wet and dry weather flows. For the case of 360 ports of 0.1016 metre diameter 3 metres apart, the initial dilution ratio of 109:1 at low current speed (0.01 m/s) and wet weather increases to 180:1 with low current speed and average dry weather flow conditions, and to 340:1 with average currents under average dry weather flow conditions. Trapping occurs at about the 20 and 10 metre heights above the diffuser, respectively.

Figure 3 presents information obtained for 360-0.1016 m, 0.1524 m, and 0.2032 m diameter ports when the average recorded flow of 5.7 m^3/s (200 cfs) is used, and all other "worst-case" conditions are maintained. In such a situation, the initial dilution ratio is increased from 109:1 to 165:1, and the trapping height above the diffuser is decreased from 33 metres to 23 metres compared to the case of wet weather flow (625 cfs) through 360-0.1016 m ports.

4.3 CURRENT DIRECTIONS

The current direction is of interest in attempting to predict the final location of the trapped or surfaced effluent. Long term records were only available for station H-26 (Figure 6) at a depth of 50 metres. These data were taken from Tabata and Strickland[4], and are summarized in Figure 8.

It is not known what effect extrapolation of these data between depths will have on their application, nor the effect of extrapolation between station H-26 and the assumed outfall location, some 2.9 kilometres further east.

4.4 DIFFUSER ORIENTATION

The DKHPLM computer model assumes that currents will be perpendicular to the diffuser section, or within a range of 20° on either side of the perpendicular direction (see Section 2.13). However, for currents below a relative angle of 45°, predictions can be made on the basis of stagnant environmental conditions[1].

Obviously, not all currents will be within the range prescribed by the DKHPLM model, however the diffuser can be oriented to capture the majority of currents within the 90° ± 20° range, or in the extreme, within the 90° ± 45° range.

Over 58 000 current directions and speeds were measured by Tabata and Strickland for the 50 metre depth at station H-26 between April 16, 1969 and July 28, 1970[4]. Data were not collected between January 23, 1970 and February 19, 1970. The direction histograms plotted by Tabata and Strickland[4] were put on one common scale, added graphically, and plotted as Figure 8. The data indicate that approximately 55 percent of currents flow in a true north/south direction ± 20°, while over 75 percent of currents flow in a true north/ south direction ± 40°. It is obvious from Figure 8 that any direction vector other than the true north/south vector would capture fewer data points. This illustrates that for direct application of the data obtained from the model, the diffuser should be oriented in a true east-west direction.

Therefore, in order that as many currents as possible flow perpendicular to the diffuser, a true east/west alignment of the diffuser sections may be preferable. However, the concept of a "Y" type diffuser may be valid when secondary dispersion effects are taken into account. This concept will not be evaluated in detail here, since other factors such as bottom stability would ultimately determine any diffuser alignment, and the diffuser section would then have to be designed accordingly.

For flows outside the range of ±45° from true north/south, stagnant conditions apply. These east/west currents will be considered in calculations of secondary dispersion and dilution in Section 4.5.

Calculations have assumed that two pipes will transport the sewage to two diffuser sections. To achieve proper spacing between the two diffusers so that adequate dilution occurs, the width of the effluent plume under "worst-case" conditions was considered. This width, which is approximately 135 metres at the highest point of rise, is the distance which should exist

between the two diffusers. This spacing has also been used in calculations for secondary dispersion.

If two parallel diffusers were laid 135 metres apart in a true east-west alignment, it is conceivable that north/south currents could cause the plume from one diffuser section to overlap the plume from the other section. The calculated initial dilution ratios would not likely be greatly affected since the initial dilution ratios have been calculated for the centreline of the plume and only the outer edges of the plume, at initial dilution ratios higher than calculated for the centreline of the plume, would overlap. The DKHPLM model takes into account the influence of adjacent ports on values determined for any individual port. Therefore any overlap effects of the separate plumes, should they develop, would likely only slightly reduce the initial dilution ratio.

As an example, the effect on initial dilution ratio of overlapping edges of the plumes might be visualized as a case where the effective port spacing is reduced. Since the actual initial dilution would be less than the initial dilution at a 3 metre spacing, the effect of overlap might approximate the average of this initial dilution and that obtained with a doubled flow/ port/metre ratio. The use of this latter reduced port spacing but with the same port exit velocity approximates a case where all the sewage is discharged from only one diffuser. Initial dilution ratios of 109:1 and 82:1 were obtained for 3 metre and 1.5 metre spacings respectively, with an exit velocity of 17.7 m^3/s. This procedure of averaging yields an average initial dilution ratio of 96:1, very close to the desired 100:1 dilution.

A 50th percentile current of 0.08 m/s decreases the field width from 135 metres to 30 metres, while a 95th percentile high current of 0.20 m/s reduces the field width to 21 metres. In these cases, the field from one diffuser would be minimally increased in terms of dilution prior to coming into contact with the field from the second diffuser, and the aforementioned example would not have to be considered. The data for a specific mass balance calculation however were not developed and the exact influence of overlapping plumes was not therefore defined.

4.5 SECONDARY DISPERSION AND DILUTION

The discharged effluent is subject to further dispersion and dilution after initial mixing. These processes are of importance in determining whether an effluent will be detrimental to a particular area such as a bathing beach. The sewage field moves with the prevailing currents, entraining seawater in the outer edges of the plume. Fischer et al.[7] cited the work of Brooks, as do many other authors, to predict the subsequent dilution. Dilution due to dispersion is calculated from:

$$D_2 = \left[\operatorname{erf} \left(\frac{1.5}{(1 + 2/3\ \beta\ \frac{x}{b})^3 - 1} \right)^{\frac{1}{2}} \right]^{-1} \quad \text{CGS units}$$

where: D_2 = dilution due to dispersion

b = width of field

x = distance from diffuser

$\beta = \frac{12\ \varepsilon o}{Vb}$

V = current speed

$\varepsilon o = 0.01\ (b)^{4/3}$

erf = standard error function

Similarly, the width of the field (Z) at any point can be calculated from:

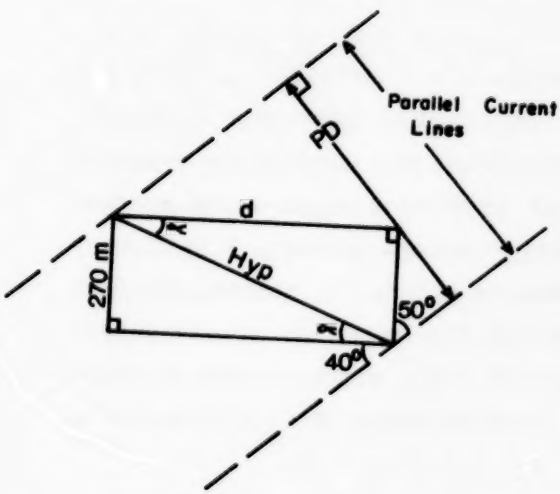
$$Z = b\ (1 + \frac{2}{3}\ \beta\ \frac{x}{b}\ )^{1.5}$$

4.5.1 CURRENTS PARALLEL TO THE DIFFUSER AND WITHIN A ±40° RANGE

If two diffuser sections are laid in the true east/west direction, separated by 135 metres, the dimension "b" will differ for two variations of the "worst-case".

VARIATION 1: In this situation, currents flow in a direction parallel to the diffuser sections. In such a case, the effective width of the field is the distance between the diffuser plus an additional half field width on each side of either diffuser, or in the study situation, a distance of 270 metres.

VARIATION 2: For all currents within about 40° from the diffuser line, except for situations governed by variation 1, the effective width of the field is calculated as the perpendicular distance (PD) between two parallel current lines which touch the extreme outer edges of the field. The length of the field (d) is calculated by adding the half width of the established field to each of the diffuser sections in addition to adding the length of the diffuser section itself. When the current angle is parallel to the diffuser sections, the distance PD becomes 270 m, as in variation 1.



The former is essentially the case of the direct transport of the plume to Iona Beach. For the case of 180 ports, 0.1016 metre in diameter and at a 3 metre spacing, the longitudinal length of field becomes:

$$d = (n - 1)\, s + 2\, b/2$$

where: d = length of field

n = number of ports in each section

s = spacing of ports

b/2 = half width of field

The length, d becomes 672 metres for all currents within about 40° from the diffuser.

With relation to the above diagram, further relevant calculations are:

$$Hyp^2 = 270^2 + 672^2$$

$$\therefore Hyp = 724 \text{ m}$$

$$\sin \alpha = \frac{270}{724} = 0.37$$

$$\therefore \alpha = 21.85°$$

If 40° is an extreme case:

$$PD = Hyp\ (\sin \alpha + 40°)$$

$$PD = 638 \text{ m}$$

Table 1 provides data for both variation 1 and variation 2, while the results have been plotted in Figure 9 for the situation where the 95 percentile high current (independent of actual duration) was used as the prevailing current. This current was used since cumulative percent frequencies could be readily calculated. For one period of record (January 9 to January 23, 1970) where direction and magnitude data were manually sorted, the 95th percentile which has been used, overestimated the magnitude of the actual 95th percentile by about 50 percent. However, this would provide an additional margin of safety since the travel times to areas of concern would be less than predicted by the calculations.

The computer model requires that for currents outside the range of ±40° from the perpendicular direction to the diffuser, stagnant conditions be applied. These conditions were applied for both variation 1 and variation 2.

The initial dilution factor for stagnant conditions was 82:1 for the "worst-case" situation where 360 ports, 0.1016 metre in diameter, were spaced at 3 metres. To obtain an initial dilution ratio of 100:1 under these conditions, a port spacing of 4.5 metres would be required. This dilution increased three to six times under additional "worst-case" conditions of a 95th percentile high current velocity causing secondary dispersion.

4.5.2 CURRENTS PERPENDICULAR TO THE DIFFUSER AND WITHIN A ±40° RANGE

The secondary dispersion and dilution associated with the predominant north/south currents are indicated in Figure 9, and are represented as variation 3 and variation 4 in Table 1. Secondary dilution effects raise the total dilution off Wreck Beach to approximately 375:1, and near the entry to Burrard Inlet and English Bay to 490:1. These dilutions would increase with decreased current velocities, or increased initial dilution ratios.

4.6 EFFECTS ON LOCAL BEACHES

It is not anticipated that under "worst-case" and high current conditions, contaminants contained in the sewage column would be detected at beach areas, except possibly for coliforms. For example, a total dilution of 219:1 would reduce the maximum effluent BOD_5 from 190 mg/L to 0.9 mg/L and total iron, the most concentrated heavy metal, from 1.4 mg/L to 0.006 mg/L, assuming dilution with uncontaminated water. However, of primary concern for contact recreation must be the bacteriological quality at the nearest beach to the outfall.

The closest beach to the outfall lies along the North Arm jetty of Iona Island. It is estimated that the shortest time of travel from the proposed outfall to the beach would be 7.6 hours (0.32 days). The bacteriological quality of the plume reaching the beach would be affected by initial dilution, secondary dilution, bacteriological "die-off" during the time of travel to the beach, as well as the initial bacteriological quality.

The effluent from the Iona STP has traditionally been chlorinated from May through September. The data in Table 2 indicate that the 90th percentile fecal coliform value recorded during the May to September period was 1030 MPN/100mL. The T_{90} values (time to obtain 90% die off) tend to increase at more northern latitudes since solar radiation is less intense and more variable. CH_2M Hill Canada Ltd.[9], in their evaluation of the Clover Point Outfall, indicated that for an English outfall located at 51°N latitude, the T_{90} ranged from a 10th percentile value of 1.1 hours to a 90th percentile value of 7.5 hours (median 3.1 hours). These values are assumed to be representative during the daytime of conditions at the proposed Iona outfall which would be located at approximately 50°N latitude.

Dilution due to bacteriological die-off (D_3)is found from:

$$D_3 = e^{\frac{2.3\ x}{T_{90}(V_x)}}$$

where: x = distance

V_x = velocity over distance

For Iona Beach, this becomes:

$$D_3 = e^{\frac{(2.3)(6365\ m)}{(7.5)(720\ m/hr)}} = e^{2.7110185}$$

$$= 15$$

Therefore, the residual bacteriological effect on Iona Beach due to the disinfected effluent during daylight would be an increase in fecal coliform of:

$$\frac{1030}{(219:1)(15:1)}\ \text{MPN} = <1\ \text{MPN/100 mL.}$$

"Sedimentation plays an important role in the process of die-away", according to B. Sterregaard[11]. As well, the effect of darkness on bacteriological die-off must be considered. Gameson and Gould[12] noted that the T_{90} value during darkness(T_D) decreased with increasing temperature, and that the applicable regression equation was:

$$\log T_D = 2.292 - 0.0295\,\theta$$

where: T_D is in hours

θ is temperature in °C.

When seawater has an ambient temperature of 7.95°C, the value for T_D is 114 hours.

These same authors also noted that there is "no die-off during the first three hours after dawn, but a rapid die-off thereafter"[12]. They summarize their findings by stating that "In situ studies, although showing that mortality rates are much higher during the day than at night, have failed to demonstrate a consistent quantitative relation between mortality rate and incident solar radiation"[12].

During darkness the value for D_3 would be only 1.2. The fecal coliform at Iona Beach would increase from <1 MPN/100 mL to 4 MPN/100 mL. This value would become 5 MPN/100 mL with no "die-off" assumed.

It was found in 1980 that the 90th percentile fecal coliform concentration in the effluent was 7 700 000 MPN/100 mL when the effluent was not disinfected. This effluent quality would increase the count during daylight at Iona Beach by about 2400 MPN/100 mL. During periods of darkness, the count would increase by about 30 000 MPN/100 mL. This value would rise to 35 000 MPN/100 mL with no "die-off" assumed. These figures indicate that disinfection of the effluent should continue during the summer months in order to minimize impact on bathing beaches. It is recognized however that the approach used in this determination is conservative. No account was taken of such environmental factors as sedimentation, chelation, osmotic

pressure differential, pH, salinity, nutrient levels, protozoa grazing, etc. and the calculations have assumed a prolonged current vector transporting bacteria directly to the beach. As well, the analysis has utilized an uncommon situation where initial dilutions were established based upon a 5 percentile low currrent, while secondary dilution effects were then based upon this initial dilution and a 5 percentile high current.

This is essentially the case for which the 135 metre diffuser separation was recommended, since the most direct transport of the plume to any sensitive shoreline would be parallel to the diffuser orientation, onto Iona Beach.

4.7 PROBABILITY OF OCCURRENCE

"The probability of a simultaneous occurrence of a number of independent events is the product of the separate probabilities"[10]. This rule was used in the following section to determine the probability of a "worst case" situation occurring.

The "worst-case" situation for the calculation of the initial dilution ratio used the three significant factors of temperature gradient, salinity gradient, and current velocity. The values chosen for these factors were based upon percentile values and cumulative percentiles, each at the 5 percent level. The probability of occurrence of wet weather flows of 17.7 m^3/s was about one day in 365 during 1981. The probability of simultaneous occurrence of all of these is:

$$P_{id} = (0.05)(0.05)(0.05)(0.0027)$$
$$= 0.0000003$$

Thus the probability of all of these conditions occurring simultaneously would be less than 0.00005%, representing an occurrence of once every 2 million days.

Calculated secondary dispersion effects have the same inherent cumulative probability as the case of initial dilution ratios. As well, secondary dispersion requires that persistent currents occur over several hours in one direction at abnormally high speeds. The 5 percentile cumulative velocity was used for these calculations, requiring that the probability of simultaneous occurrence calculated for the initial dilution be modified so that:

$$P_{SD} = (P_{id})(0.05)$$
$$= 0.000000015$$

This calculated statistical occurrence is representative of the event occurring once every 40 million days.

When maximum effluent concentrations are taken into account, the further probability factor of 0.01 must be considered. This figure would then be used to further modify the P_{SD} value.

The entire analysis has shown that the "worst-case" conditions for secondary dispersion and initial dilution are unlikely to occur simultaneously. However, since bacteriological quality was shown to be severely degraded in the earlier analysis, without effluent disinfection, there is decidedly a need for a major safety factor for beach protection. The degree of conservatism inherent in this approach could conceivably relieve the need for summer-time disinfection, depending upon the order of "acceptable risk" applied.

4.8 DESIGN CHECKS

4.8.1 MINIMUM VELOCITY CHECK (PIPE)

MINIMUM VELOCITY IN PIPE: must be maintained $\geq$ 0.3 m/s to prevent deposition of sewage solids.

At ADWF: each 2.032 m pipe carries 2.31 m^3/s

: each pipe (flowing full) has area of:

π (1.016 m)^2 = 3.24 m^2

: Velocity = $\frac{2.31}{3.24}$ = 0.71 m/s

At minimum recorded flow since 1975 (160 000 m^3/d):

Velocity in each pipe = $\frac{(80\ 000\ m^3/d)}{(24)(3600)(3.24 m^2)}$ = 0.29 m/s

4.8.2 COMPARISON WITH OTHER EXISTING OUTFALLS

Comparisons between the Iona design and other long sea outfalls in Table 3 highlight the following:

(1) The length of diffuser proposed is almost identical to that in Honolulu (Sand Island) for the same design average flow.

(2) Port diameters proposed at Iona Island have not been calculated precisely taking into account pressure differentials etc., but are in the same range as those in Honolulu (Sand Island).

(3) Port spacing proposed at Iona Island is closer than used at Honolulu (Sand Island).

(4) Discharge velocity for average flows would be less than at all other outfalls.

(5) The discharge per unit length ratio proposed for Iona Island is nearly identical to the Honolulu (Sand Island) outfall.

(6) The port to pipe area factor is nearly identical to factors for three other outfalls. (City of Los Angeles at Hyperion, Sanita-

tion Districts of Orange County, Calif., and Honolulu, Sand Island.)

(7) It was also noted that the most favourable comparisons were obtained with the more modern outfalls, and with Honolulu in particular.

5. REVIEW OF OTHER DIFFUSER OPTIONS

As part of the study, an assessment was made of a discharge through a shorter outfall to an intermediate water depth. For this purpose, a diffuser location towards the edge of the tidal platform of the Bank in about 9 metres of water was considered.

5.1 TECHNICAL FEASIBILITY

The main design factors affecting the feasibility of an outfall on the Bank are identified in Chapters 2 and 3.

In brief, a total length of 6 797 metres of outfall, inclusive of twin diffuser sections each 548 metres long, would be required to relocate the discharge from the present location to intermediate water depths. Depending on the selected orientation, the diffusers would discharge to a maximum of 10 metres of water or to a range of depths varying from 3 to 10 metres. The Iona jetty would provide a convenient foundation for the works to a distance of 4 725 metres from shore.

The tidal flats are relatively smooth with an average slope in the order of 0.1% and characterized by sand-size sediments. Surface currents, which might be expected to exert a major control in the dispersion of the effluent plume, are commonly in the range of 0.2 to 0.5 metres per second. Water movement south of the jetty is generally seaward on ebb tides and landward in flood tides, with disruptions in this overall pattern occurring randomly as a result of local and seasonal influences. Low wind speeds can significantly affect surface layer conditions. In calm weather, a thin brackish layer of surface water can persist in the shallows, south of the Iona jetty.

As indicated previously, there is little indication from the present geologic and oceanographic data that any significant impediment exists to the construction of a shallow outfall across the Bank. As far as

hydraulic equalization and pipeline construction are concerned, there are definite advantages over deep-sea design. There are, however, concerns that exaggerated sand-bed movement over the flats would complicate pipe bedding and pipeline stability in general. This effect would be expected to be most pronounced at the shoulder of the foreshore drop-off. As a secondary consequence of a shifting sand bed, maintenance of the discharge ports may need to be more frequent to ensure unobstructed, uniform effluent flow and distribution.

5.2 PRELIMINARY DIFFUSER DESIGN

As in the deep-sea diffuser concept, the DKHPLM computer model was utilized for the intermediate depth diffuser. Because of the possible variations in diffuser alignment, two distinct analyses were undertaken for the prediction of "worst-case" conditions. For one situation the diffuser was assumed to lie in a north-south alignment, uniformly submerged in approximately 10 metres of water. The second case related to an east-west diffuser at an average depth of about 7 metres.

For both cases new salinity and temperature gradients were developed using data from station H-23N (Figure 6).

5.2.1 INITIAL DILUTION

At the 10 metre depth, the mean ambient temperature was 7.49°C (n=42) and the mean salinity was 27.33 ppt (n=42). Linear gradients for each of these parameters, at the 95th percentile limit, were -0.0128°C/m and -1.43 ppt/m, respectively. Although surface currents are commonly faster than those at depth, a velocity of 0.01 metres per second was used, as in the earlier deep-sea analysis, to enable comparison and accentuate the "worst-case". Using twin diffusers at a depth of 10 metres, with identical configuration as with the deep-sea outfall but in the north-south alignment, an initial dilution of 27:1 was predicted with trapping of the plume occurring about 4 metres below the surface. Increasing port spacings from 3 metres to 9 metres increased the initial dilution to only 31:1.

Modifying the design to accord with available measurements for an average 7 metre diffuser submergence in an east-west alignment, a "worst-case" condition was simulated by assuming complete mixing of the plume with the receiving seawater over at least a portion of the discharge zone. This resulted on the use of a mean salinity value of 22.23 ppt and an ambient temperature of 6.72°C throughout the 7 metre depth of water. Zero salinity and temperature gradients were assumed. On this basis, an initial dilution of 40:1 was demonstrated with the plume reaching the surface. It should be noted that these values were calculated using an ambient current velocity increased from 0.01 m/s to 0.02 m/s. This procedural modification was required to overcome precision errors which caused rounding off of values to zero, features inherent in the computer model for this situation.

5.2.2 SECONDARY DISPERSION

A "worst-case", high current velocity was extrapolated from survey information to provide an appropriate surface velocity of 0.4 metres per second. This current speed was applied in both cases of intermediate diffuser depths. The differences in secondary dilutions resulted essentially from the variation in the initial plume dilutions at each location and the distance from the selected landmarks. The secondary dilutions derived are shown below, together with the associated travel time, and the comparative results from the deep-sea outfall computations.

Location	Diffuser at 10 metres, North-South		Diffuser at 7 metres average, East-West		Diffuser at 65 metres depth	
	Dilution	Travel Time	Dilution	Travel Time	Dilution	Travel Time
Iona Beach	45:1	3.6 hrs.	60:1	3.4 hrs.	220:1	9.0 hrs.
Sea Island	75:1	4.6 hrs.	106:1	4.3 hrs.	475:1	9.5 hrs.
Wreck Beach	50:1	5.3 hrs.	76:1	5.3 hrs.	370:1	11.0 hrs.
Burrard Inlet	65:1	7.0 hrs.	94:1	7.0 hrs.	490:1	14.0 hrs.

5.3 DISCUSSION

As discussed in Section 4.7, the dilution ratios presented above have a low probability of occurrence, primarily due to the prolonged current vectors used. The ratios therefore may be conservative in absolute terms but are nevertheless valuable for comparison.

The purpose of examining the diffuser under the two sets of conditions is to assess the varying conditions which exist in the shallow waters. One can expect a stratified environment to be better maintained at the deeper, 10 metre depth, resulting in the plume being trapped below the surface, but with less initial dilution. However, the mixing action of internal waves and the natural oscillation of the density gradients themselves are likely at times to create non-stratified conditions causing the plume to surface, as demonstrated in the east-west diffuser design. Average conditions therefore, for either diffuser orientation might be reasonably represented by a combination of the two cases, depending on the controlling environmental factors present. There is no significant distinction in potential effects between the two diffuser orientations in the shallow waters over Sturgeon Bank.

6. RECOMMENDATIONS

1. An initial dilution ratio of 100:1 under most conditions should form the design target to obtain adequate dilution and dispersion of effluent.

2. To obtain an initial dilution of 100:1 under most conditions, the design will probably need 360 ports of 0.1016 metre (4 inch) diameter (or equivalent port area) at a spacing of 3 metres with a diffuser alignment in a true east-west direction.

3. The concept of a "Y" diffuser should be considered when factors of secondary dispersion effects and bank stability are taken into account.

4. The need for summertime effluent disinfection should depend upon the degree of "acceptable risk" associated with bacteriological contamination of beach areas. A continuation of the present disinfection practice will provide a major safety factor under most conditions and a sufficient safety factor under "worst-case" conditions, for the protection of beaches closest to the outfall.

5. A thorough engineering study and environmental impact study of any long sea outfall considered must be undertaken prior to a final decision being made on construction.

7.0 SUMMARY

A preliminary assessment was carried out in order to gain some understanding of factors influencing a design of a long sea outfall and the potential impact on the environment from such an installation. The DKHPLM computer model was used to predict initial dilutions for various diffuser configurations while secondary dispersion effects were computed manually. It is believed that the DKHPLM model will provide predicted dilutions and trapping heights which are conservative, relative to those actually measured under field conditions.

It was determined that initial dilution ratios were strongly influenced by discharge velocity, current velocity, ambient temperature and salinity gradients, port diameter, and port spacing.

Over 58 000 measurements which had been taken within about three kilometres (two miles) from the assumed location of the outfall at a depth of 50 metres were used to estimate ambient temperatures, ambient currents, and ambient current directions. Forty-two measurements which had been obtained at five depths down to 50 metres at a second station in the same general vicinity were used to estimate linear salinity and temperature gradients. A data summary for the Iona STP effluent quality was used. It included values which had been determined daily, monthly, once in every three days, or twice in every three days, depending upon the need for and limitations of the particular analysis.

An initial dilution ratio of about 100:1 for most conditions was used as the basis for diffuser design. As well, it was assumed that the sewage would be transported through two pipes, -2.03 metre (80 inch) diameter, in a straight east-west line extending from the present Iona Island jetty to an average depth of 65 metres. A "worst-case" situation was defined as sewage with a temperature of 12°C and salinity of 0.3 ppt, being discharged at a flow of 17.7 m^3/s into seawater with a low current speed of 0.01 m/s, at a

temperature of 7.95°C, a salinity of 29 ppt, and having associated temperature and salinity gradients of 0.024°C/m and -0.024 ppt/m respectively. Using this "worst-case" it was determined that a 100:1 dilution could be attained using 360 ports, -0.1016 metre (4 inch) diameter, at a 3 metre spacing, or 455 ports, -0.1016 metre (4 inch) diameter, at a 2 metre spacing. The plume was trapped 33 metres above the ports. The former spacing was recommended since it gave excellent correlation with an operating outfall.

Initial dilution ratios were dramatically improved if effluent flow rates were reduced, or current speeds increased relative to the "worst-case". When both of these conditions occurred simultaneously, the initial dilution ratio increased to about 340:1.

Currents occurred predominantly in a north-south direction, with about 55 percent of the currents flowing within 20° of either side of true north-south, and over 75 percent within 40° of either side of true north-south. This indicated that the diffuser orientation should be east-west to take advantage of currents perpendicular to the diffuser that give the best initial dilution ratio. However, the concept of "Y" diffuser sections may yet be valid when secondary dispersion effects are taken into account. Diffuser orientation will also depend upon other design factors such as bottom foreshore stability.

Secondary dispersion effects were estimated using "worst-case" initial dilution subjected to a 95th percentile high velocity current, thereby giving "worst-case" conditions for the secondary dilution effects. This resulted in overall dilutions of 219:1 at Iona Beach, 475:1 at Sea Island, 375:1 at Wreck Beach, and 490:1 entering Burrard Inlet. Dilutions of 219:1 would reduce the maximum effluent BOD_5 from 190 mg/L to 0.9 mg/L, and the total iron, the most concentrated heavy metal, from 1.4 mg/L to 0.006 mg/L. With disinfection of the effluent, the fecal coliform level at Iona Beach would increase by about 5 MPN/100 mL over background assuming no bacteriological "die-off" during transport. Without disinfection of the effluent, this value would rise to about 35 000 MPN/100 mL.

The statistical probability of the "worst-case" condition for initial dilution is about one in 2 million, based upon the frequency of maximum wet weather flow recorded during 1980. The probability was decreased by a factor of twenty to also allow for "worst-case" secondary dispersion effects occurring simultaneously, a situation totally unlikely to occur.

The suggested design for the deep-sea outfall for the Iona Island STP was similar in many respects to the existing Honolulu (Sand Island) deep-sea outfall.

A review of other possible options for the diffuser revealed that for discharges at a depth of 10 metres, an initial dilution of 27:1 would be obtained with the effluent trapping 4 metres below the surface. Secondary dispersion effects would increase the dilution to 75:1 at Sea Island or 65:1 at Burrard Inlet. Increased port spacing from 3 to 9 metres marginally increased the initial dilution ratio from 27:1 to 31:1.

The placement of the diffuser in 7 metres of water with zero salinity and temperature gradients caused the effluent to surface at an initial dilution ratio of 40:1. Secondary dispersion effects caused the dilution to increase to 106:1 at Sea Island and 94:1 at Burrard Inlet.

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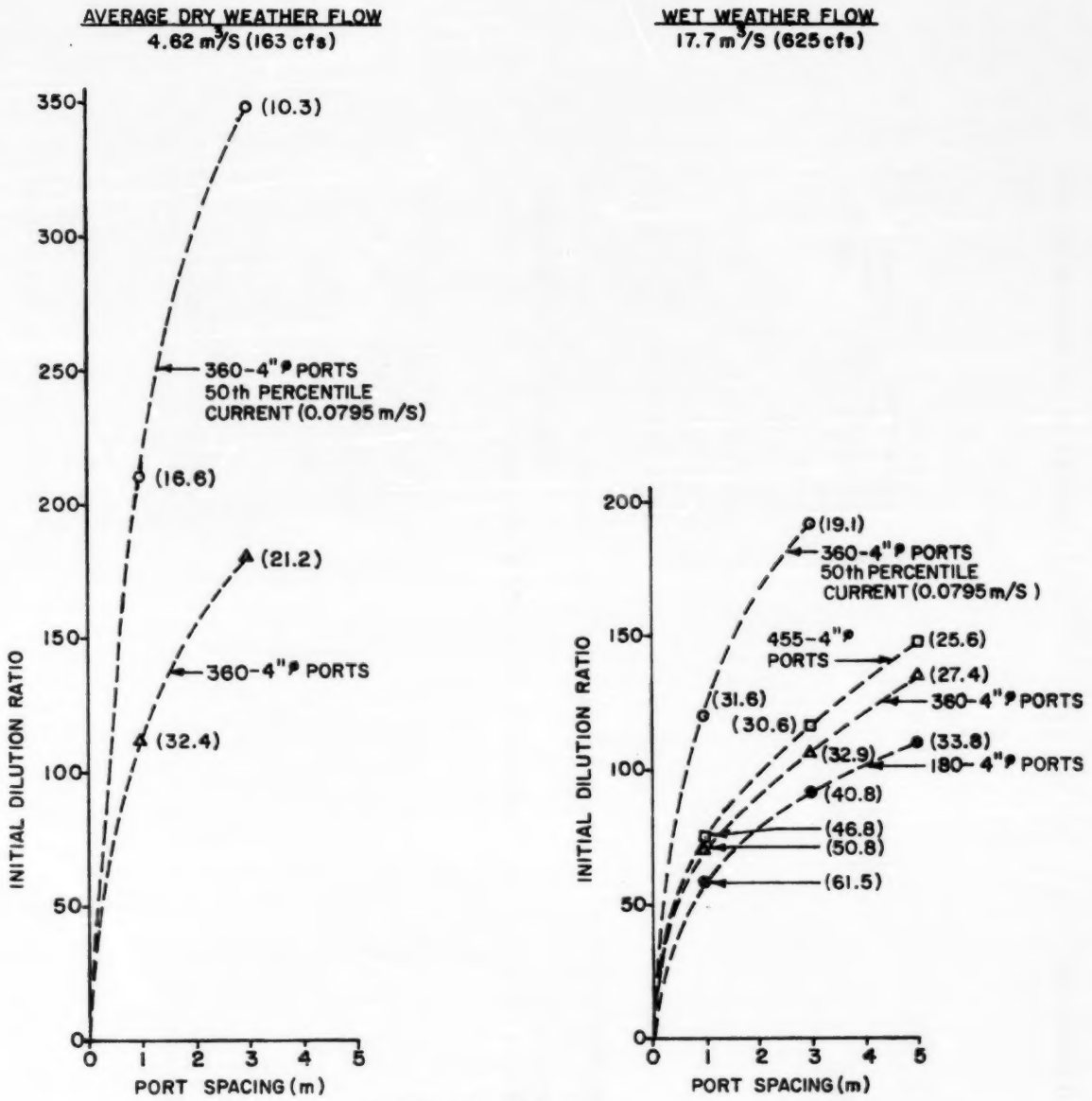


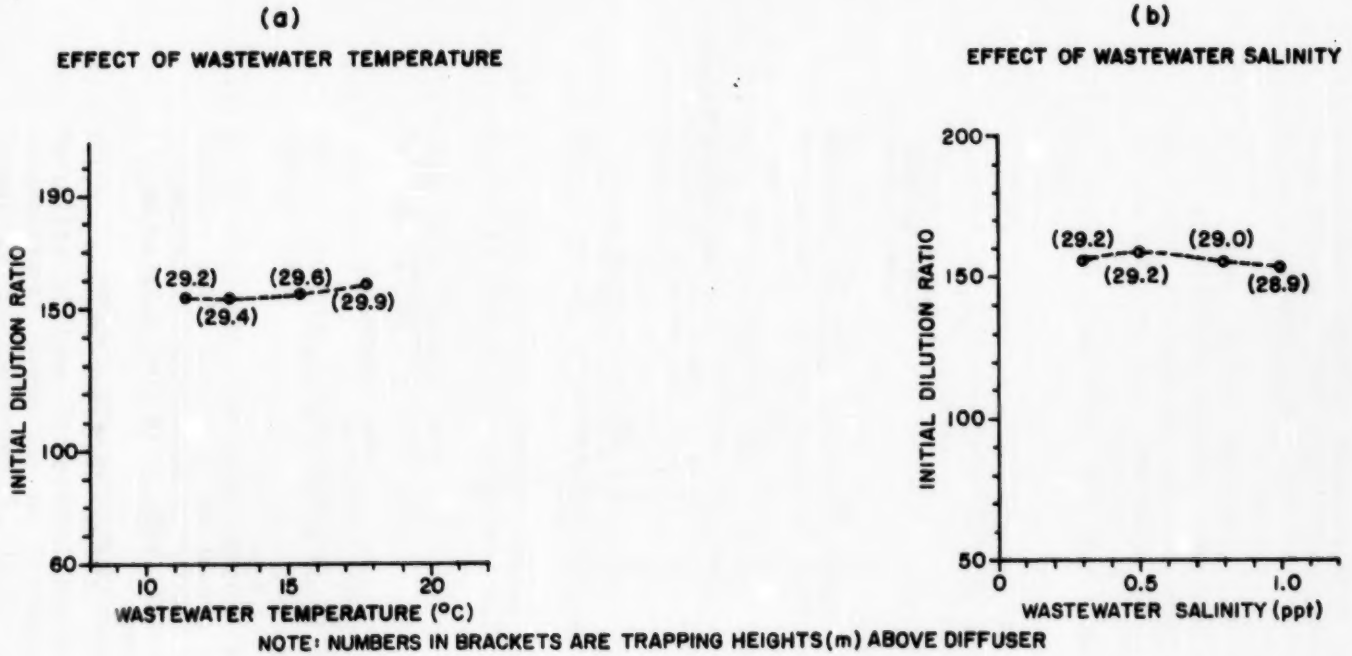
NOTES TO FIGURE 1

( ) NUMBERS IN BRACKETS REFER TO TRAPPING HEIGHT (m) ABOVE DIFFUSER

CONDITIONS USED : EFFLUENT TEMPERATURE : 12°C
SALINITY : 0.3 ppt
AMBIENT TEMPERATURE : 7.95°C
SALINITY : 29 ppt
TEMPERATURE GRADIENT : (5%)(50 TO 30m) : 0.024°C/m
SALINITY GRADIENT : (95%)(50 TO 30 m) – 0.024 ppt /m

DIFFUSER DEPTH : 65 METRES
CURRENT VELOCITY : 0.01 m/S UNLESS OTHERWISE INDICATED

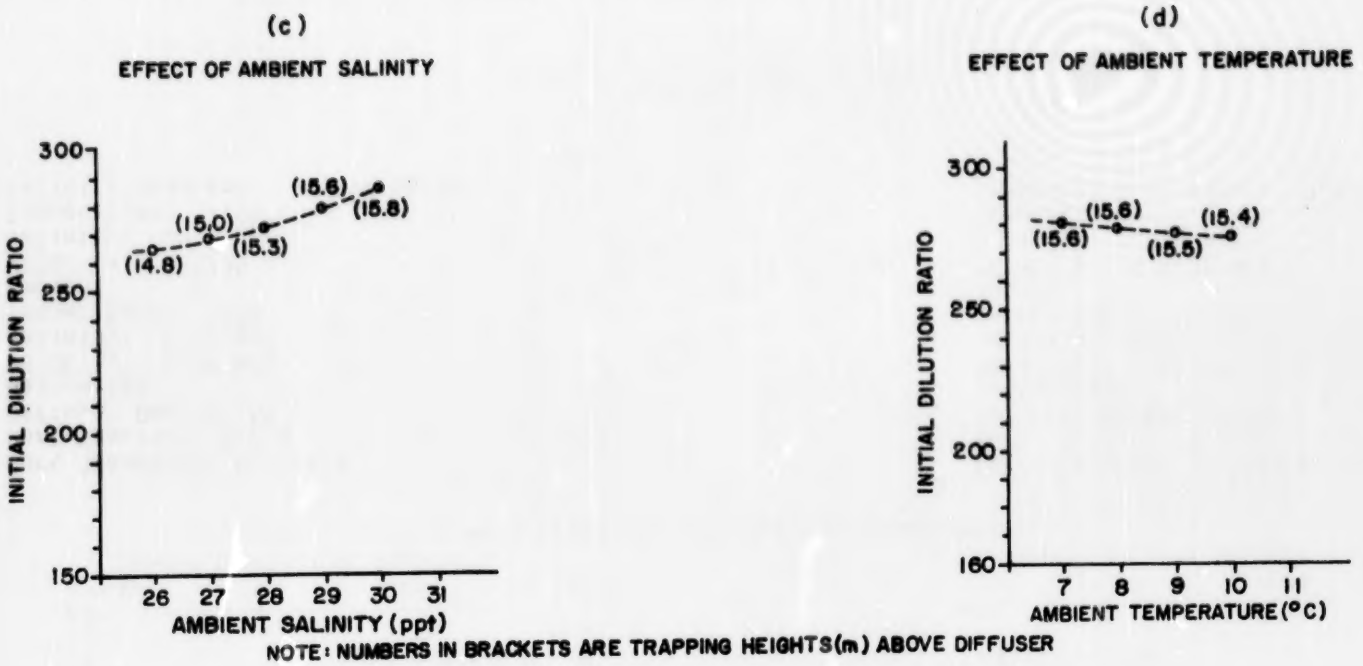
FIGURE 1 . INITIAL DILUTION RATIOS AT WET AND DRY WEATHER FLOWS



Port Diameter: 0.1524 m
Port Spacing: 3.0 m
Diffuser Depth: 65 m
Wastewater:
Velocity: 5.38 m/s
Salinity: 0.30 ppt
Ambient:
Velocity: 0.0795 m/s
Temperature: 7.95°C
Salinity: 29.0 ppt
Temperature Gradient: 0.03°C/m
Salinity Gradient: -0.018 ppt/m

Port Diameter: 0.1524 m
Port Spacing: 3.0 m
Diffuser Depth: 65 m
Wastewater:
Velocity: 5.38 m/s
Temperature: 12.0°C
Ambient:
Velocity: 0.0795 m/s
Temperature: 7.95°C
Salinity: 29.0 ppt
Temperature Gradient: 0.03°/m
Salinity Gradient: -0.018 ppt/m

FIGURE 2. EFFECT ON INITIAL DILUTION RATIO OF VARYING PARAMETERS



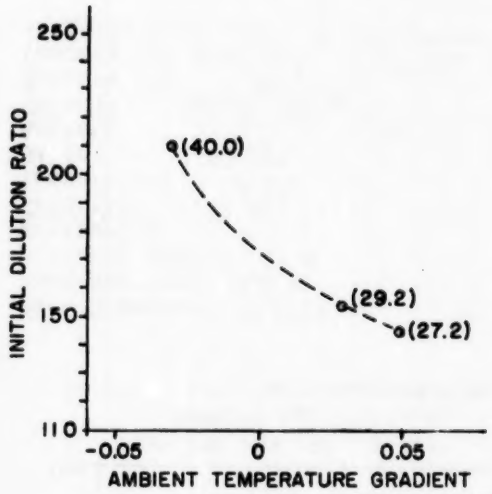
Port Diameter: 0.1524 m
Port Spacing: 3.0 m
Diffuser Depth: 65 m
Wastewater:
Velocity: 5.38 m/s
Temperature: 12.0°C
Salinity: 0.30 ppt
Ambient:
Velocity: 0.0795 m/s
Temperature: 7.95°C
Temperature Gradient: 0.03°C/m
Salinity Gradient: -0.018 ppt/m

Port Diameter: 0.1524 m
Port Spacing: 3.0 m
Diffuser Depth: 65 m
Wastewater:
Velocity: 5.38 m/s
Salinity: 0.30 ppt
Temperature: 12.0°C
Ambient:
Velocity: 0.0795 m/s
Salinity: 29.0 ppt
Temperature Gradient: 0.03°/m
Salinity Gradient: -0.018 ppt/m

FIGURE 2 (Cont'd). EFFECT ON INITIAL DILUTION RATIO OF VARYING PARAMETERS

(e)

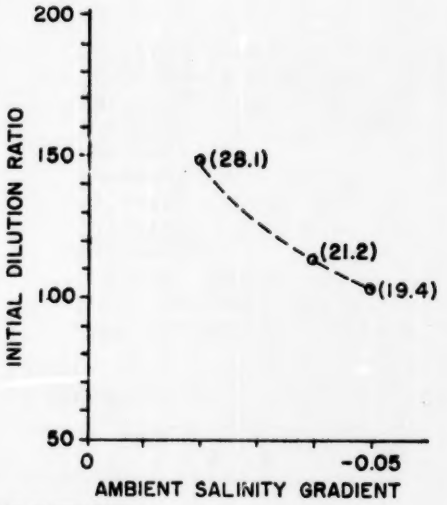
EFFECT OF AMBIENT TEMPERATURE GRADIENT



Port Diameter: 0.1524 m
Port Spacing: 3.0 m
Diffuser Depth: 65 m
Wastewater:
Velocity: 5.38 m/s
Salinity: 0.30 ppt
Temperature: 12°C
Ambient:
Velocity: 0.0795 m/s
Salinity: 29.0 ppt
Temperature: 7.95°C
Salinity Gradient: -0.018 ppt/m

(f)

EFFECT OF AMBIENT SALINITY GRADIENT



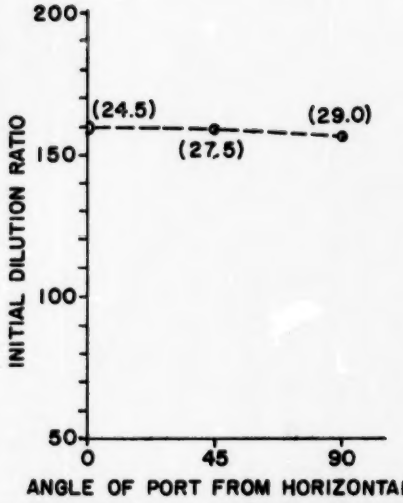
Port Diameter: 0.1524 m
Port Spacing: 3.0 m
Diffuser Depth: 65 m
Wastewater:
Velocity: 5.38 m/s
Salinity: 0.30 ppt
Temperature: 12.0°C
Ambient:
Velocity: 0.0795 m/s
Salinity: 29.0 ppt
Temperature: 7.95°C
Temperature Gradient: 0.03°C/m

NOTE: NUMBERS IN BRACKETS ARE TRAPPING HEIGHTS (m) ABOVE DIFFUSER

FIGURE 2 (Cont'd) . EFFECT ON INITIAL DILUTION RATIO OF VARYING PARAMETERS

(g)

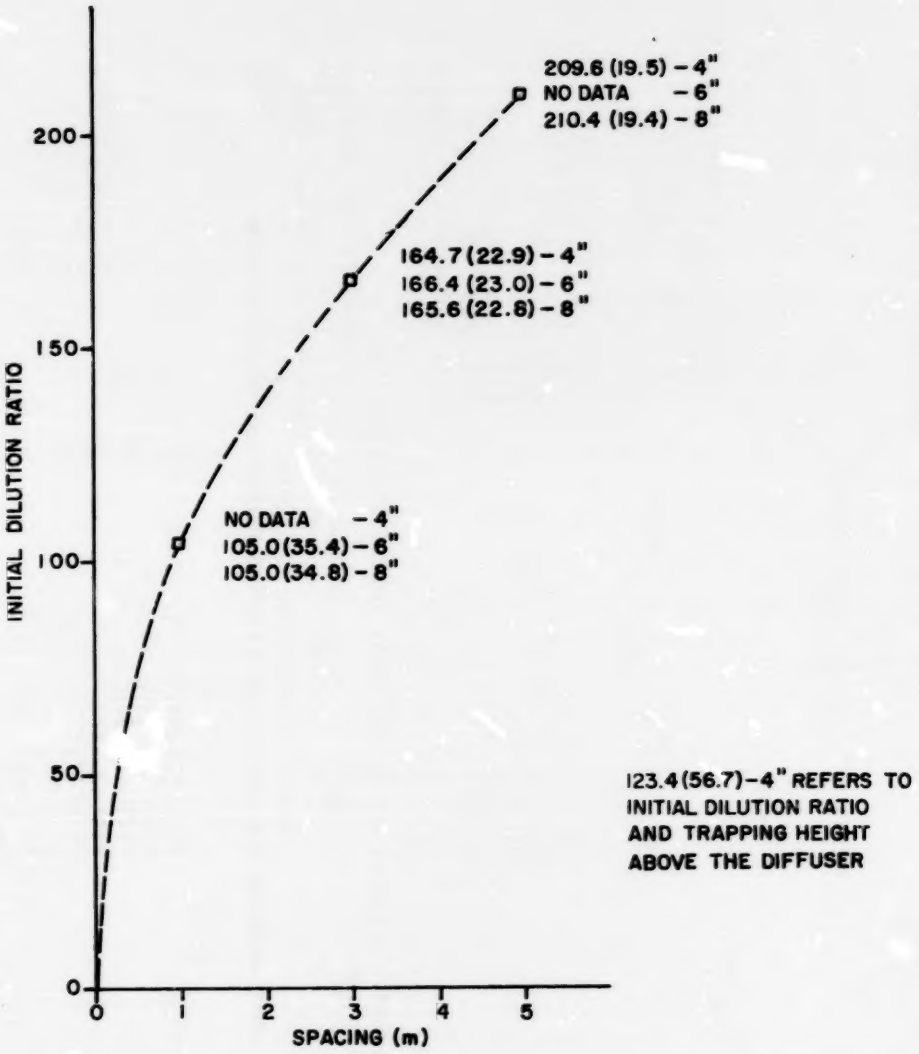
EFFECT OF ALTERING ANGLE OF PORT FROM HORIZONTAL



NOTE: NUMBERS IN BRACKETS ARE TRAPPING HEIGHTS (m) ABOVE DIFFUSER

Port Diameter: 0.1524 m
Port Spacing: 3.0 m
Diffuser Depth: 65 m
Wastewater:
Velocity: 5.38 m/s
Salinity: 0.30 ppt
Temperature: 12°C
Ambient:
Velocity: 0.0795 m/s
Temperature: 7.95°C
Salinity: 29.0 ppt
Temperature Gradient: 0.03°C/m
Salinity Gradient: -0.018 ppt/m

FIGURE 2 (Cont'd) . EFFECT ON INITIAL DILUTION RATIO OF VARYING PARAMETERS



EFFLUENT : TEMPERATURE : 12.0 °C
SALINITY : 0.3 ppt
AMBIENT : TEMPERATURE : 7.95 °C
SALINITY : 29.0 ppt
TEMPERATURE GRADIENT : 0.024 °C/m
SALINITY GRADIENT : – 0.024 ppt
CURRENT VELOCITY : 0.01 m/s
DIFFUSER DEPTH : 65 METRES

FIGURE 3 . INITIAL DILUTION RATIOS FOR VARIOUS SPACINGS AND PORT DIAMETERS UNDER AVERAGE ANNUAL FLOWS OF 5.7 m^3/s (200 CFS) THROUGH 360 PORTS

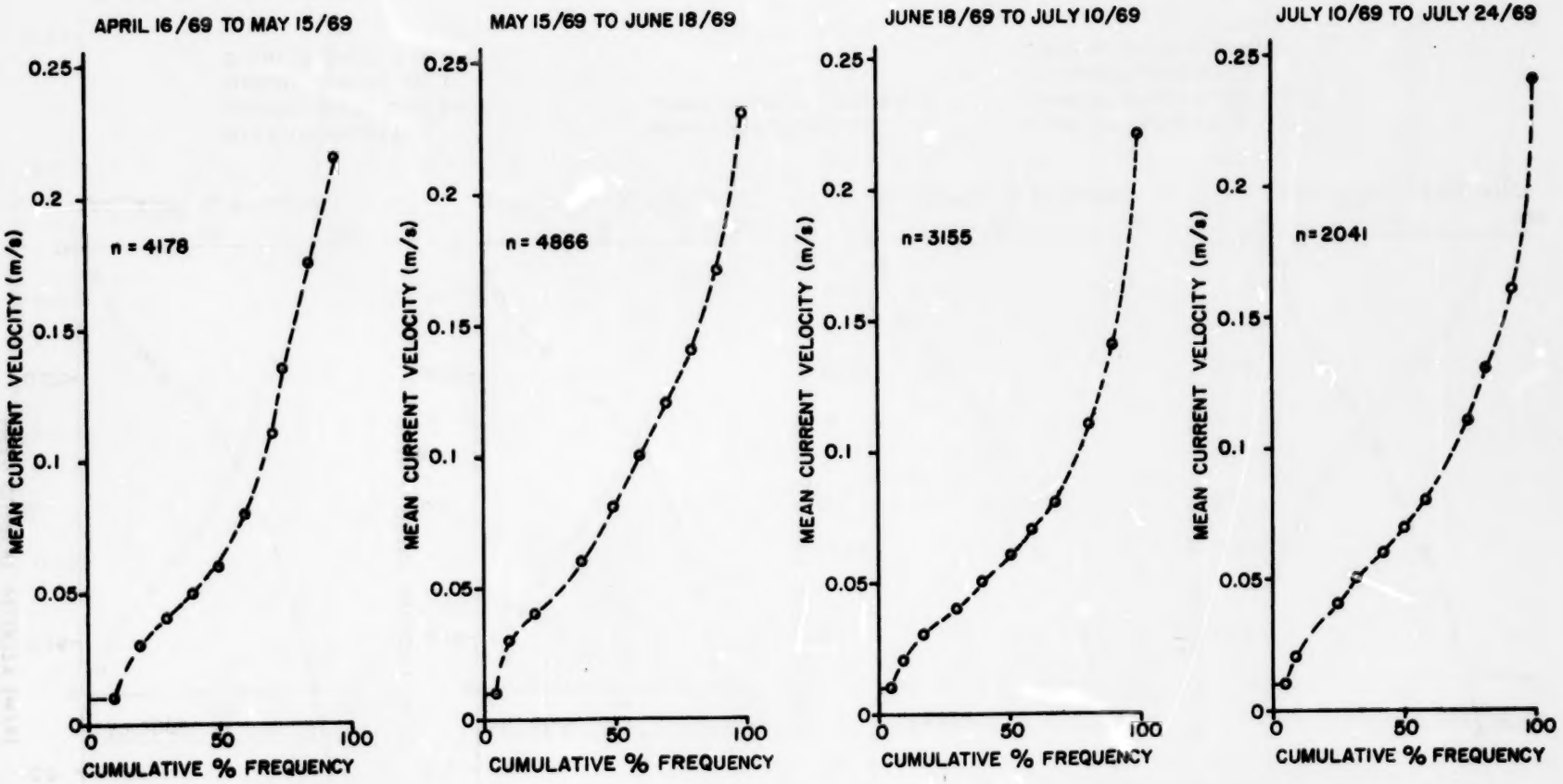
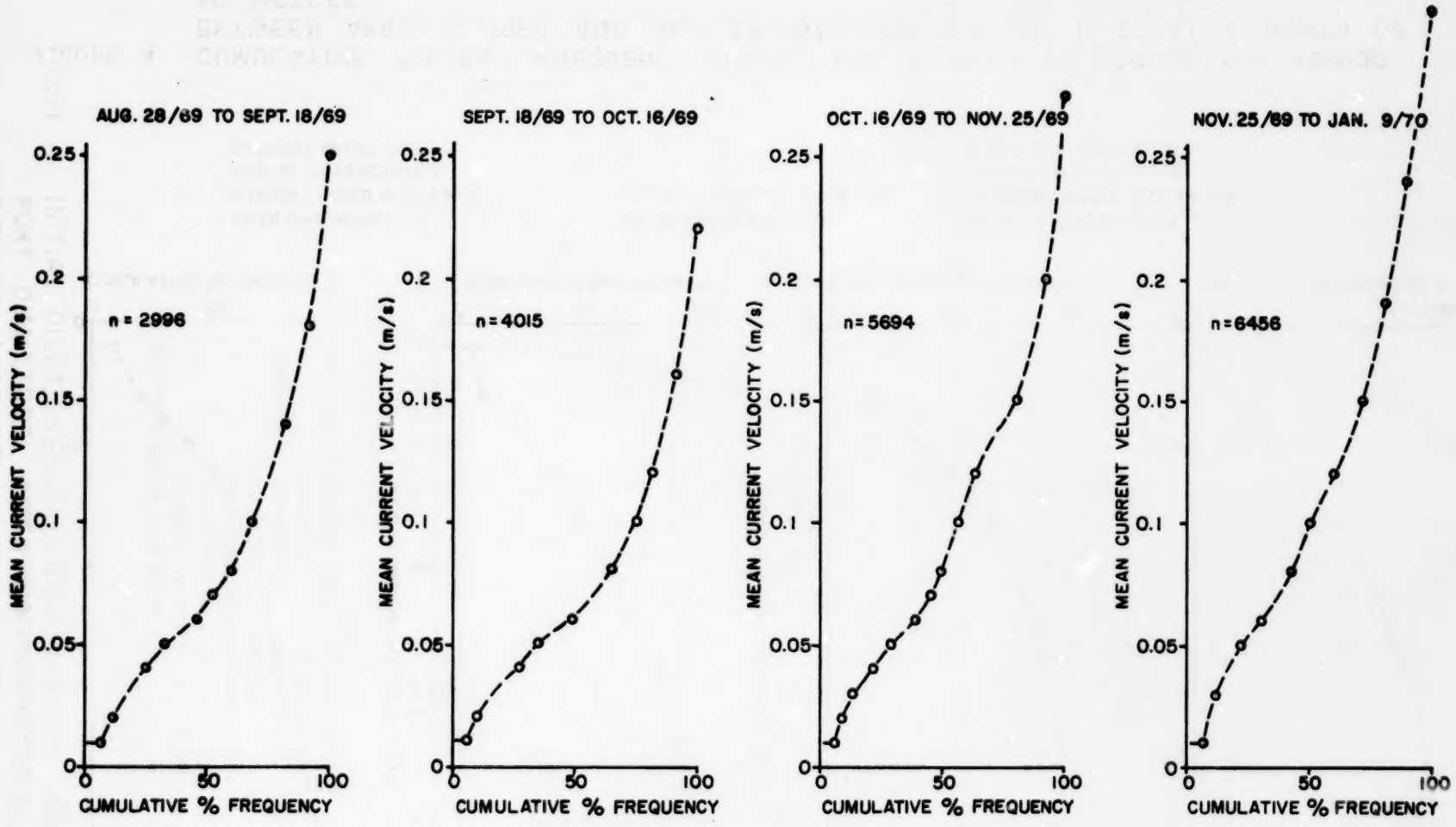


FIGURE 4 CUMULATIVE PERCENT FREQUENCY CURVES FOR CURRENT VELOCITIES FOR PERIOD BETWEEN APRIL 16, 1969 AND JULY 28, 1970 FOR STATION H-26 AT A DEPTH OF 50 METRES

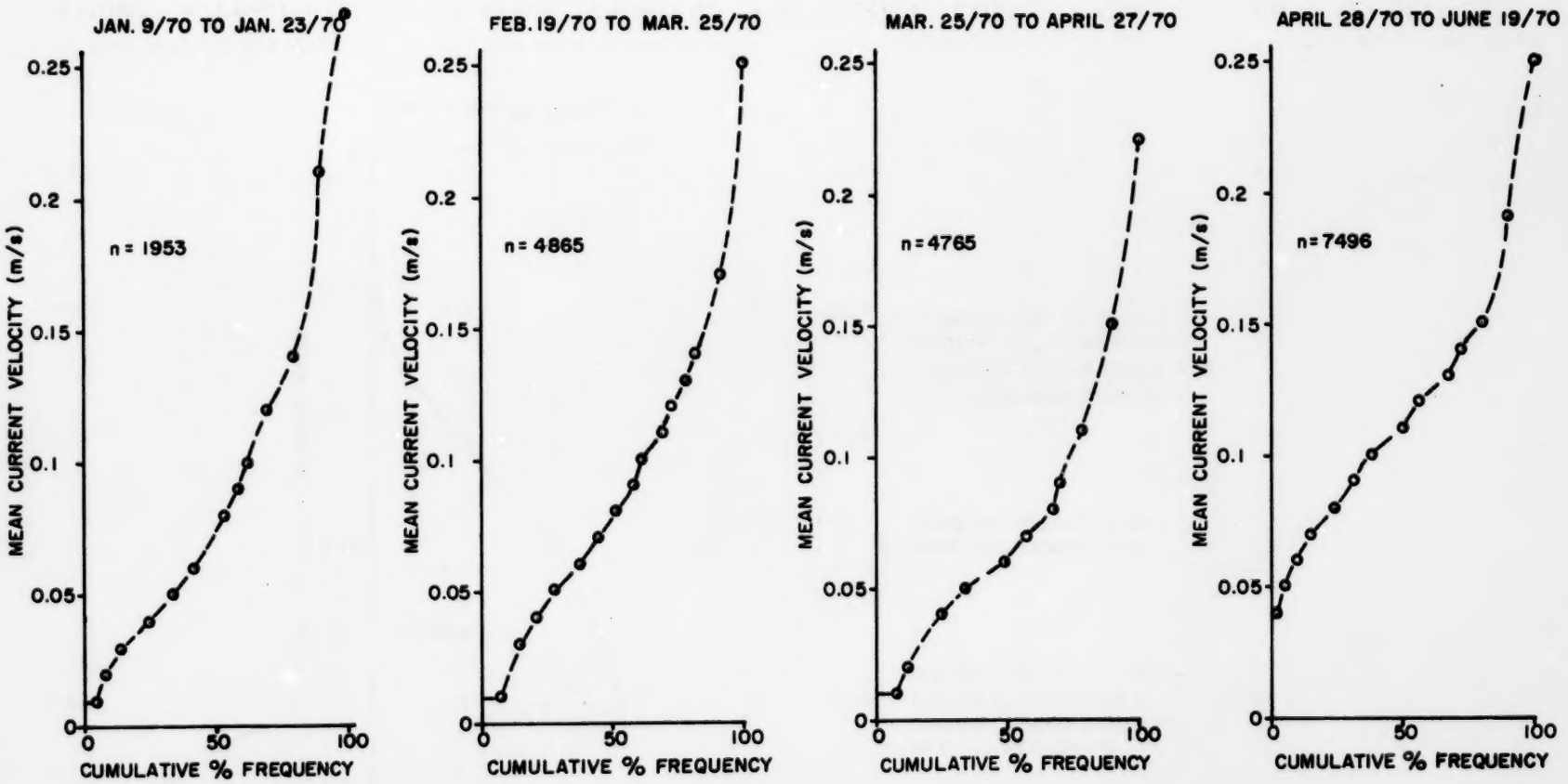


MEAN 5th PERCENTILE
CURRENT SPEED 0.0173 m/s
MEDIAN 5th PERCENTILE
CURRENT SPEED 0.01 m/s

MEAN 50th PERCENTILE
CURRENT SPEED 0.0795 m/s

MEAN 95th PERCENTILE
CURRENT SPEED 0.0204 m/s
MEDIAN 95th PERCENTILE
CURRENT SPEED 0.20 m/s

FIGURE 4 (Cont'd) CUMULATIVE PERCENT FREQUENCY CURVES FOR CURRENT VELOCITIES FOR PERIOD BETWEEN APRIL 16, 1969 AND JULY 28, 1970 FOR STATION H-26 AT A DEPTH OF 50 METRES

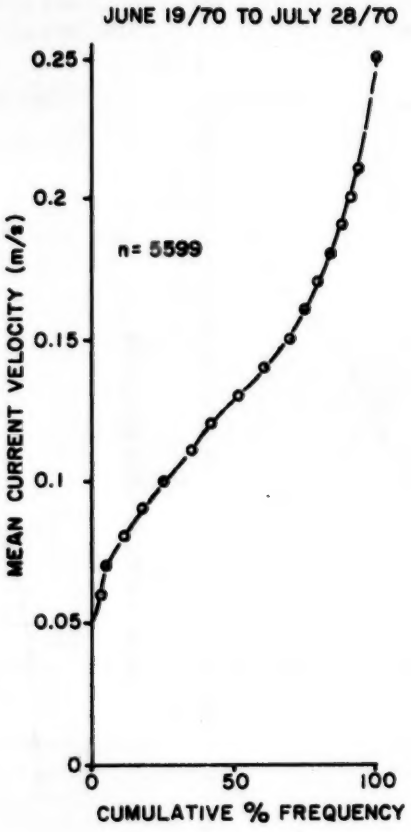


MEAN 5th PERCENTILE
CURRENT SPEED 0.0173 m/s
MEDIAN 5th PERCENTILE
CURRENT SPEED 0.01 m/s

MEAN 50th PERCENTILE
CURRENT SPEED 0.0795 m/s

MEAN 95th PERCENTILE
CURRENT SPEED 0.0204 m/s
MEDIAN 95th PERCENTILE
CURRENT SPEED 0.20 m/s

FIGURE 4 (Cont'd). CUMULATIVE PERCENT FREQUENCY CURVES FOR CURRENT VELOCITIES FOR PERIOD BETWEEN APRIL 16, 1969 AND JULY 28, 1970 FOR STATION H-26 AT A DEPTH OF 50 METRES



MEAN 5th PERCENTILE
CURRENT SPEED 0.0173 m/s
MEDIAN 5th PERCENTILE
CURRENT SPEED 0.01 m/s

MEAN 50th PERCENTILE
CURRENT SPEED 0.0795 m/s

MEAN 95th PERCENTILE
CURRENT SPEED 0.204 m/s
MEDIAN 95th PERCENTILE
CURRENT SPEED 0.20 m/s

FIGURE 4 (Cont'd). CUMULATIVE PERCENT FREQUENCY CURVES FOR CURRENT VELOCITIES FOR PERIOD BETWEEN APRIL 16, 1969 AND JULY 28, 1970 FOR STATION H-26 AT A DEPTH OF 50 METRES

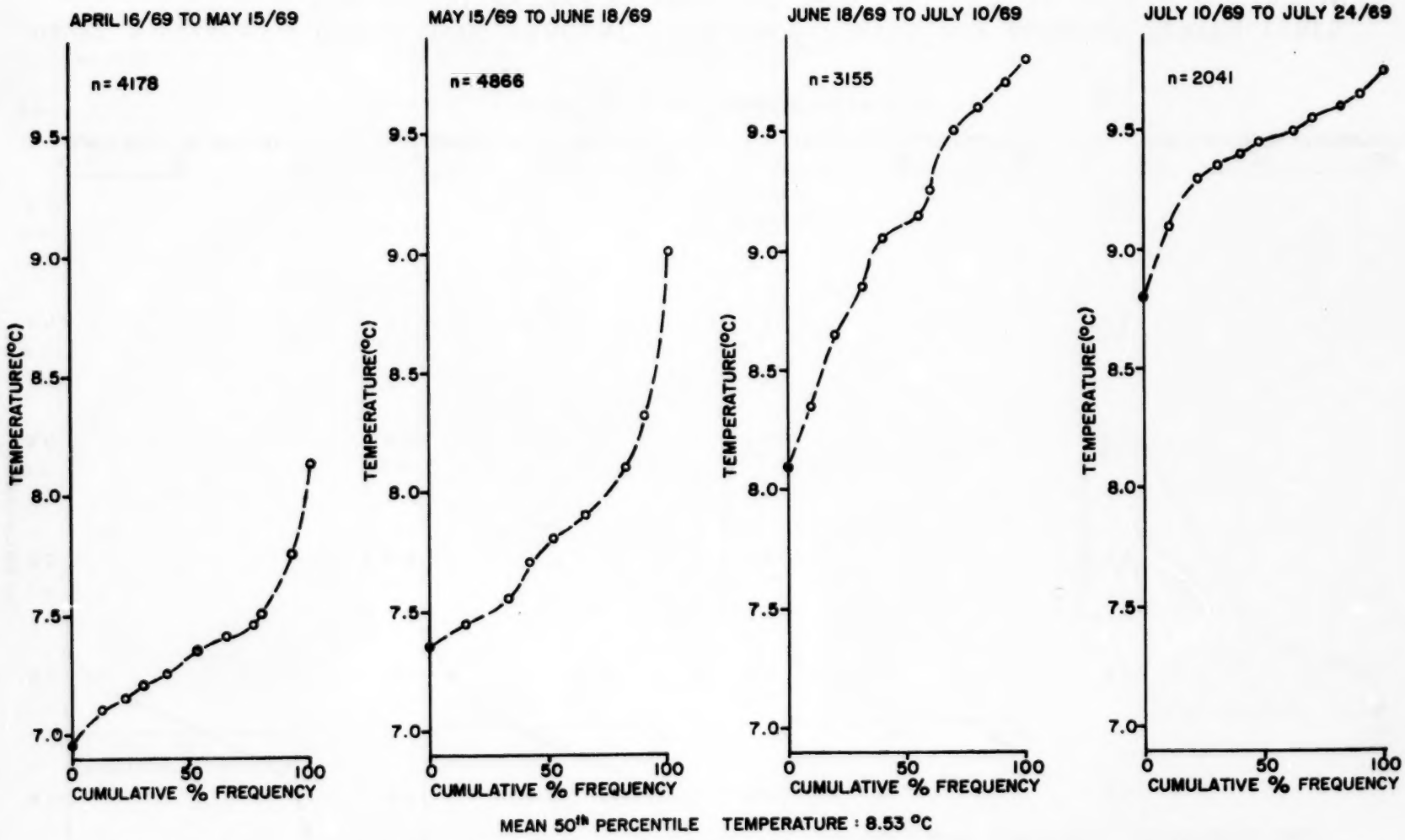


FIGURE 5 . CUMULATIVE PERCENT FREQUENCY CURVES FOR AMBIENT TEMPERATURES FOR PERIOD BETWEEN APRIL 16, 1969 AND JULY 28 , 1970 FOR STATION H-26 AT A DEPTH OF 50 METRES

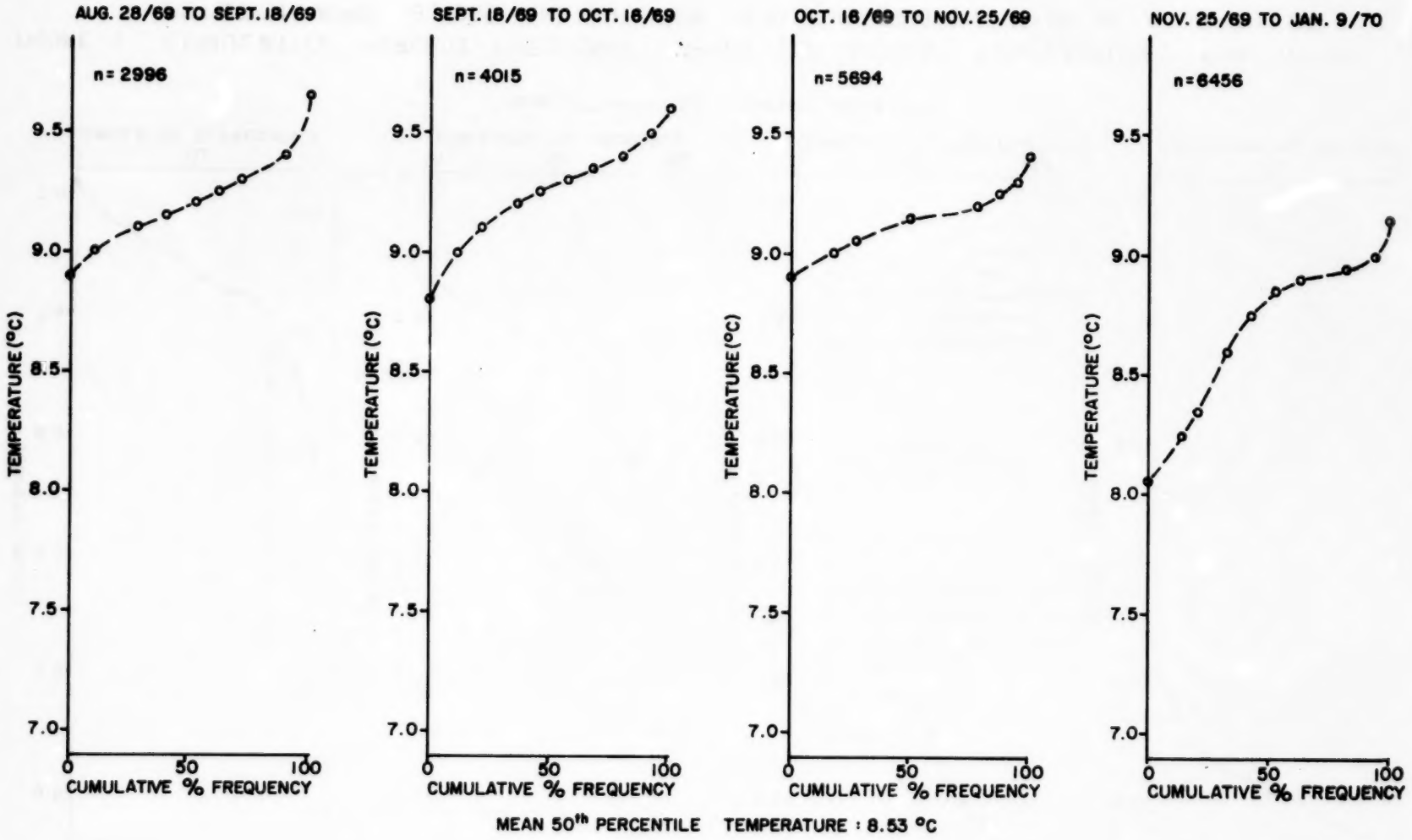


FIGURE 5 (Cont'd) CUMULATIVE PERCENT FREQUENCY CURVES FOR AMBIENT TEMPERATURES FOR PERIOD BETWEEN APRIL 16, 1969 AND JULY 28, 1970 FOR STATION H-26 AT A DEPTH OF 50 METRES

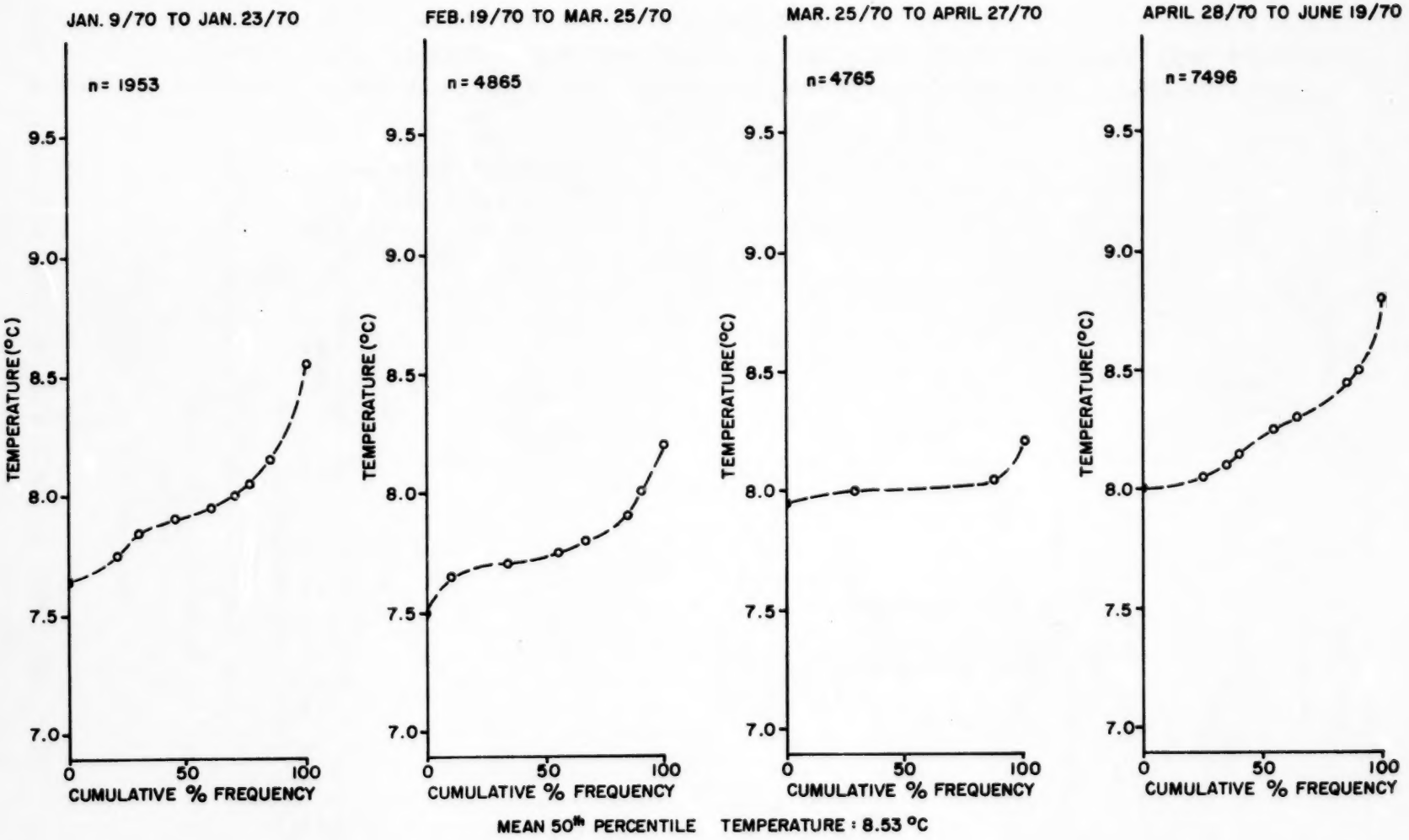
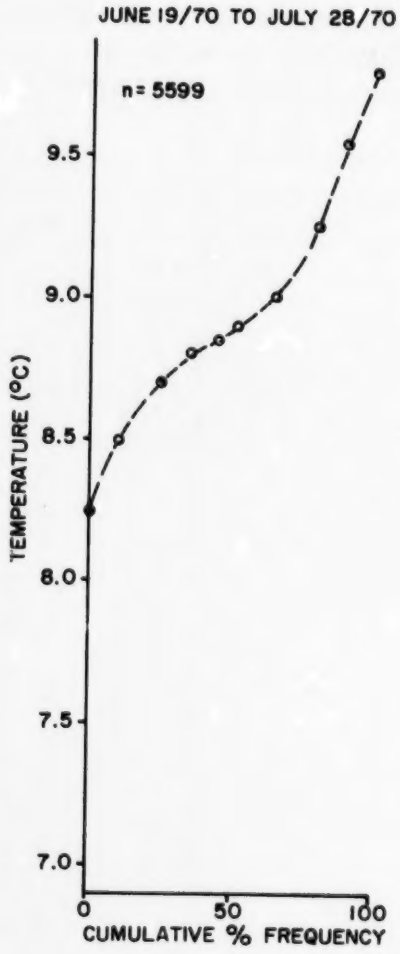


FIGURE 5 (Cont'd). CUMULATIVE PERCENT FREQUENCY CURVES FOR AMBIENT TEMPERATURES FOR PERIOD BETWEEN APRIL 16, 1969 AND JULY 28, 1970 FOR STATION H-26 AT A DEPTH OF 50 METRES



MEAN 50th PERCENTILE

TEMPERATURE : 8.53 °C

FIGURE 5 (Con t'd) . CUMULATIVE PERCENT FREQUENCY CURVES FOR AMBIENT TEMPERATURES FOR PERIOD BETWEEN APRIL 16, 1969 AND JULY 28, 1970 FOR STATION H-26 AT A DEPTH OF 50 METRES

FIGURE 6 . LOCATION MAP OF STATIONS H-23N AND H-26

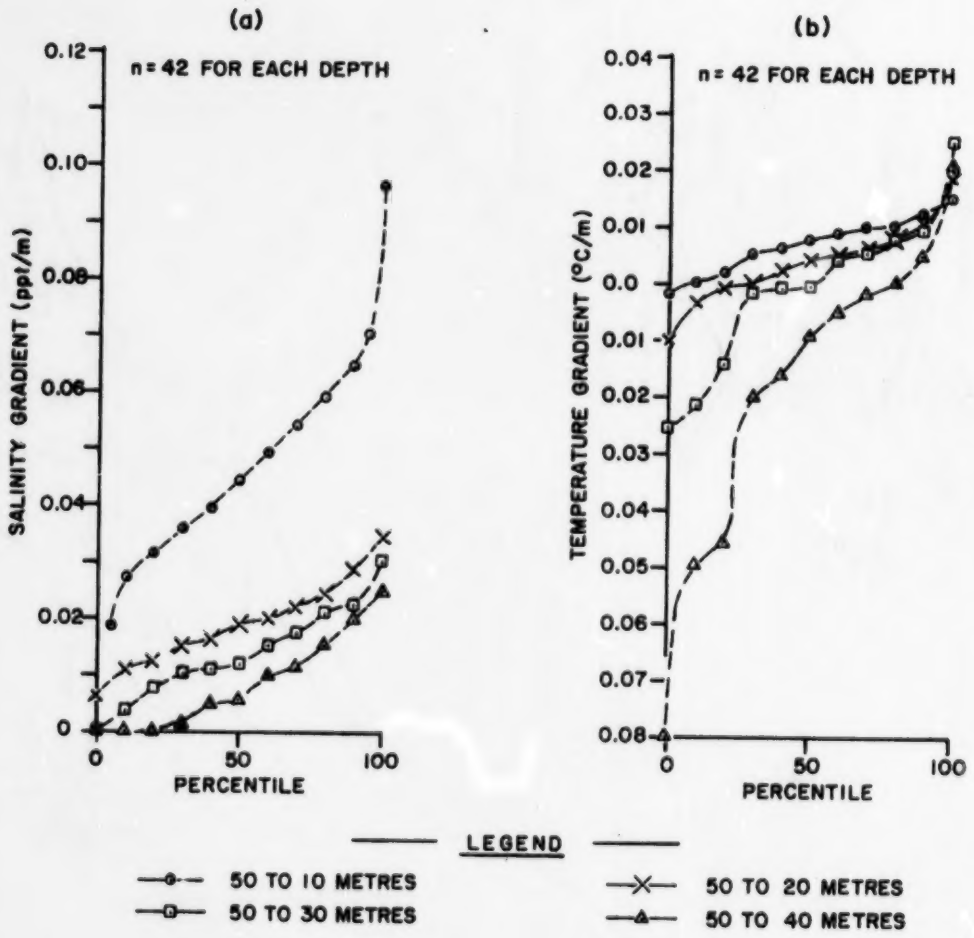


FIGURE 7 PERCENTILE CURVES FOR SALINITY AND TEMPERATURE GRADIENTS BETWEEN MARCH 13, 1968 AND MARCH 15, 1968 FOR STATION H-23N BETWEEN 50 METRES DEPTH AND EACH OF 40, 30, 20 AND 10 METRES

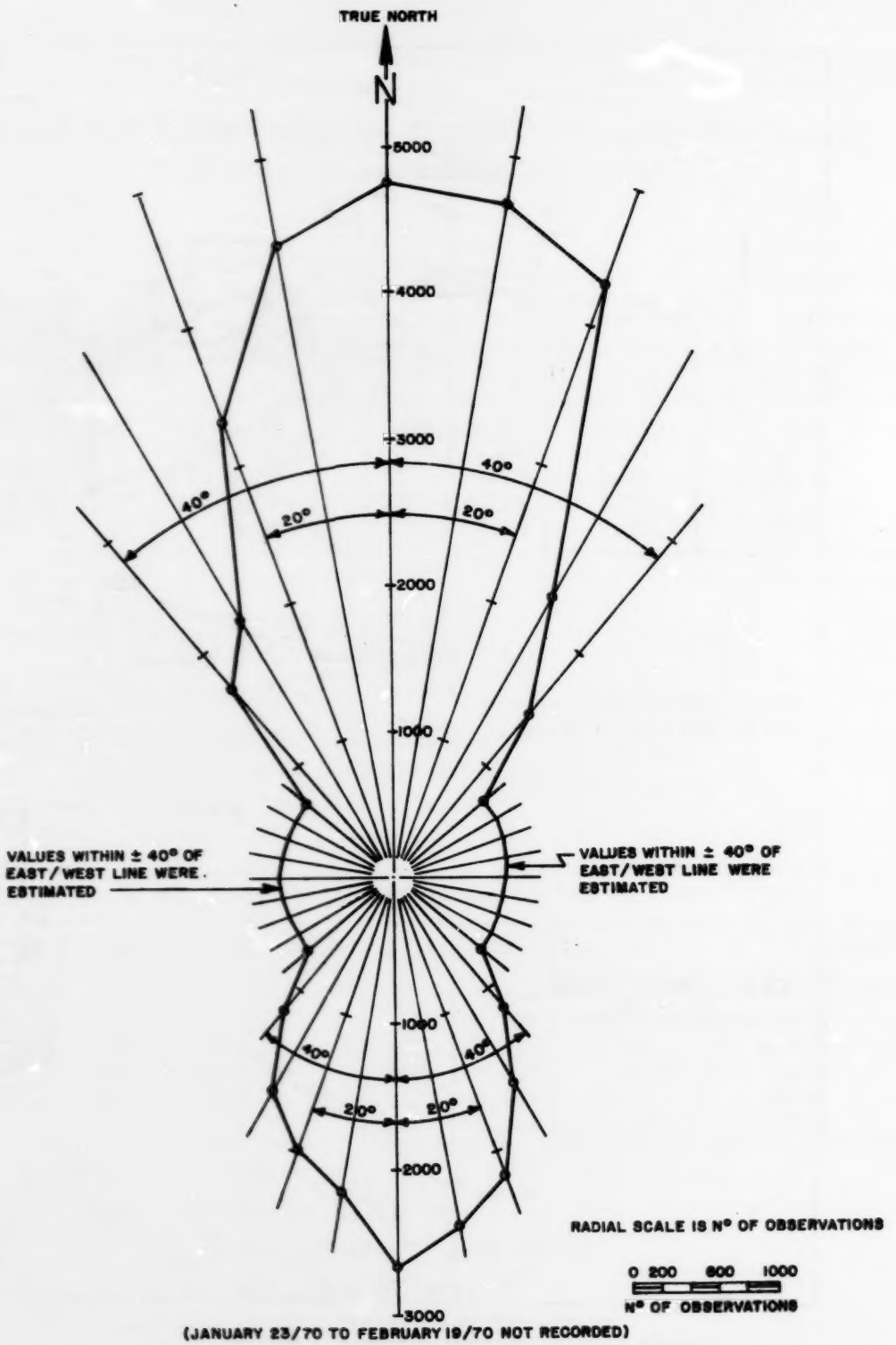


FIGURE 8 . CUMULATIVE HISTOGRAM FOR CURRENT DIRECTIONS BETWEEN APRIL 15, 1969 AND JULY 28, 1970 FOR STATION H-26 AT A DEPTH OF 50 METRES

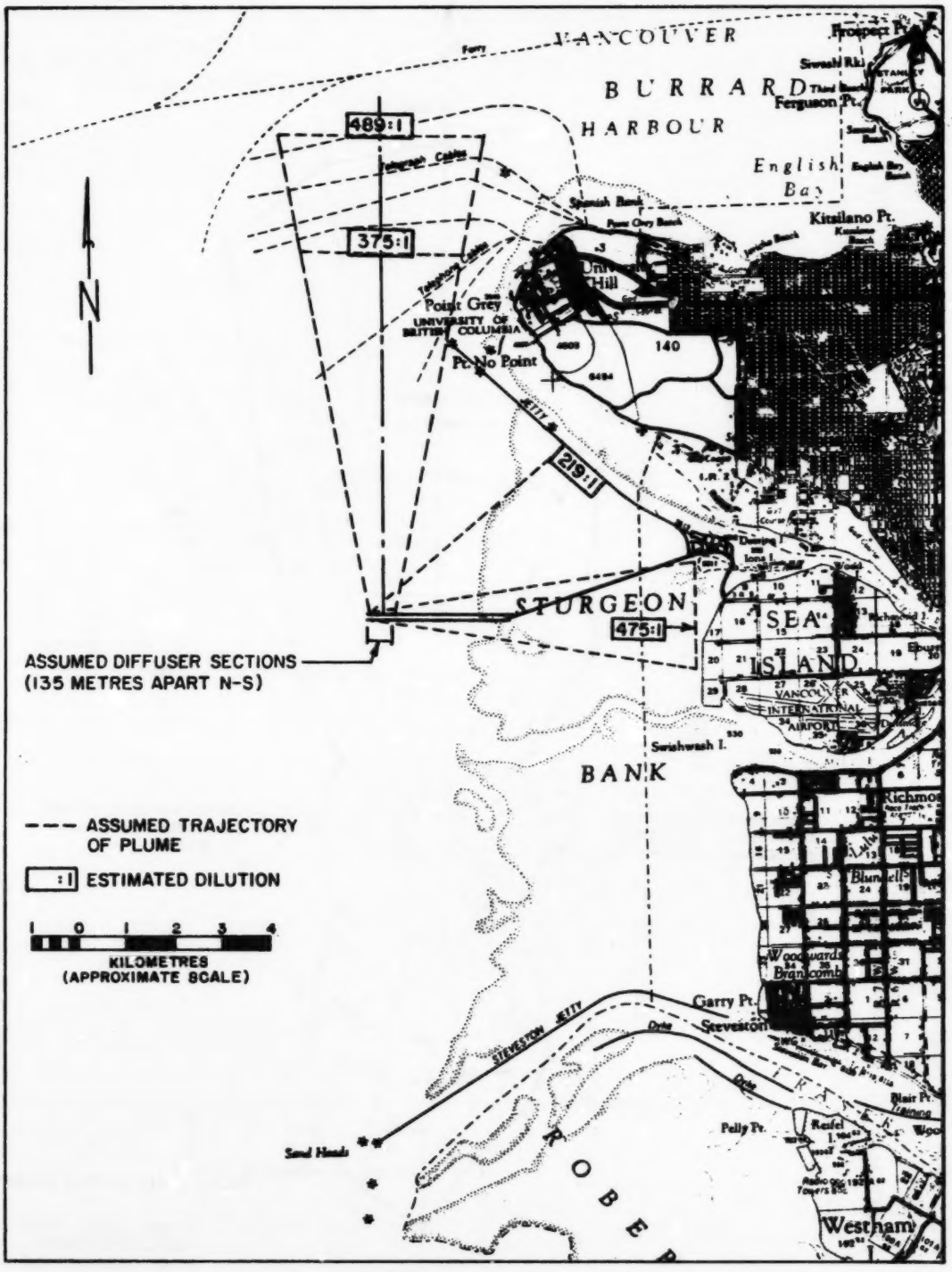


FIGURE 9 . SECONDARY DISPERSION EFFECTS AND DILUTIONS FOR FIFTH PERCENTILE HIGH TRUE NORTHERLY AND EASTERLY CURRENTS WHEN THE IONA STP IS EXPERIENCING "WORST-CASE" CONDITIONS

TABLE 1: SECONDARY DISPERSION AND DILUTION FOR 95th PERCENTILE CURRENT (0.20 m/s) AT STATION H-26 (50 METRES)

Variation 1 - True Easterly or Westerly Current						
t (hrs)	x (m)	(1 + 2/3 β x/b)	Z (m)	C/Co	D_2 = Co/C	Total Dilution $D \cdot D_2$
1	720	1.32	409	0.871	1.15	94:1
3	2160	1.96	741	0.501	2.00	163:1
5	3600	2.60	1132	0.329	3.04	249:1
7	5040	3.24	1575	0.244	4.10	335:1
9.58	6900	4.07	2217	0.172	5.81	475:1

where: $b = 270\ m = 27\ 000\ cm;$

$\varepsilon o = 0.01\ (27\ 000)^{4/3} = 8100;$

$U = 0.20\ m/s = 20\ cm/s;$

and $\beta = \frac{12\ \varepsilon o}{Ub} = \frac{(12)(8100)}{(20)(27\ 000)} = 0.18$

Variation 2 - Range of Current Direction True East/West ± 40°						
t (hrs)	x (m)	(1 + 2/3 β x/b)	Z (m)	C/Co	D_2 = Co/C	Total Dilution $D \cdot D_2$
1	720	1.18	818	0.968	1.03	84:1
3	2160	1.54	1221	0.711	1.41	115:1
5	3600	1.90	1675	0.525	1.90	156:1
7	5040	2.26	2173	0.405	2.47	202:1
7.6	5500	2.39	2357	0.373	2.68	219:1

where: $b = 638\ m = 63\ 800\ cm;$

$\varepsilon o = 0.01\ (63\ 800)^{4/3} = 25\ 493.38;$

$U = 0.20\ m/s = 20\ cm/s;$

and $\beta = \frac{12\ \varepsilon o}{Ub} = \frac{(12)(25\ 493.38)}{(20)(63\ 800)} = 0.24$

TABLE 1 (Continued)

Variation 3 - True North South						
t (hrs)	x (m)	(1 + 2/3 β x/b)	Z (m)	C/Co	D_2 = Co/C	Total Dilution D • D_2
6.9	5000	2.21	2208	0.42	2.38	259:1
10.5	7500	2.82	3190	0.291	3.44	375:1

where: b = 672 m = 67 200 cm;

$\varepsilon o = 0.01\ (67\ 200)^{4/3} = 27\ 320$;

U = 0.20 m/s = 20 cm/s;

and $\beta = \frac{12\ \varepsilon o}{Ub} = \frac{(12)(27\ 320)}{(20)(67\ 200)} = 0.244$

Variation 4 - Range of Current Direction: True North/South $\geq$ 40°						
t (hrs)	x (m)	(1 + 2/3 β x/b)	Z (m)	C/Co	D_2 = Co/C	Total Dilution D • D_2
6.9	5000	2.19	2233	0.425	2.35	255:1
10.5	7500	2.80	3223	0.294	3.40	371:1
14.0	10000	3.40	4305	0.223	4.48	489:1

where: b = 688 m = 68 800 cm;

$\varepsilon o = 0.01\ (68\ 800)^{4/3} = 28\ 191$;

U = 0.20 m/s = 20 cm/s;

and $\beta = \frac{12\ \varepsilon o}{Ub} = \frac{(12)(28\ 191)}{(20)(68\ 800)} = 0.246$

TABLE 2: IONA ISLAND S.T.P. EFFLUENT QUALITY

Parameter (2)	Type Sample (1)	Period Covered by Data	Number of Samples	Range	Percentile Distribution		
					10th	50th	90th
B.O.D.	C	Jan 77 - Dec 80	450	30 - 190	62	97	140
Suspended Solids	C	Jan 77 - Dec 80	1302	18 - 180	27	50	70
pH	G	Jan 77 - Dec 80	909	5.8 - 9.5	6.5	6.9	7.3
Dissolved Oxygen	G	Jan - Dec 80	240	0.6 - 9.8	2.9	4.5	7.3
Chlorine Residual	G	Apr 18 - Oct 7/80	216	0.1 - 3.9	0.3	1.1	1.9
Fecal Coliforms MPN/100 mL	G	Apr 18 - Oct 7/80	64	<30 - 460 000	<30	110	1030
Fecal Coliforms MPN/100 mL	G	Jan 1 - Apr 17, Oct 8 - Dec 31/80	71	9300 - 46 x 10^6	230 000	1 180 000	7 700 000
Oil and Grease	G	Mar 77 - Oct 81	52	5 - 73	8.5	19.5	40
Phenolics	G	Mar 77 - Oct 81	54	<0.01 - 0.32	<0.01	0.02	0.04
Dissolved Sulphides	G	Sep 77 - Oct 81	32	ALL <0.06	<0.06	<0.06	<0.06
TLM 96%	G	Jan 79 - Oct 81	34	80.6 - >100	>100	>100	89.7
Kjeldahl Nitrogen N	C	Mar 77 - Oct 81	53	5.0 - 29.0	8.5	16.0	22.0
Ammonia Nitrogen N	C	Mar 77 - Oct 81	52	1.5 - 17.0	3.8	8.7	13.6
Nitrate and Nitrite N	C	Jan 78 - Oct 81	43	ALL <2	<2	<2	<2
Dissolved Phosphorus	C	Mar 77 - Oct 81	51	0.3 - 3.0	0.6	1.8	2.6
Total Phosphorus	C	Mar 77 - Oct 81	51	1.0 - 4.0	1.3	2.7	3.6
Total Cyanide	G	Mar 77 - Oct 81	53	<0.02 - 0.11	<0.02	<0.02	0.02
M.B.A.S.	C	Mar 77 - Oct 81	52	0.1 - 2.0	0.3	1.0	1.5
Total Aluminum	C	Mar 77 - Oct 81	51	0.2 - 2.0	0.3	0.8	1.2
Total Arsenic	C	Apr 77 - Oct 81	46	ALL <0.02	<0.02	<0.02	<0.02
Dissolved Barium	C	May 77 - Oct 81	45	ALL <0.05	<0.05	<0.05	<0.05
Dissolved Boron	C	May 77 - Oct 81	41	0.03 - 0.34	0.09	0.16	0.28
Dissolved Cadmium	C	Mar 77 - Oct 81	45	<0.0005 - 0.0036	<0.0005	0.0013	0.0028
Total Chromium	C	Mar 77 - Oct 81	53	<0.05 - 0.09	<0.05	<0.05	0.06
Dissolved Cobalt	C	Mar 77 - Oct 81	52	ALL <0.05	<0.05	<0.05	<0.05
Total Copper	C	Apr 78 - Jan 79	39	<0.04 - 0.41	0.06	0.11	0.15
Dissolved Copper	C	Mar 77 - Oct 81	53	<0.04 - 0.25	<0.04	0.05	0.10
Total Iron	C	Apr 78 - Jan 79	39	0.56 - 1.40	0.62	0.76	0.97
Dissolved Iron	C	June 77 - Oct 81	50	0.10 - 0.70	0.19	0.36	0.58
Total Lead	C	Mar 77 - Oct 81	53	0.007 - 0.12	0.012	0.032	0.074
Dissolved Manganese	C	May 77 - Oct 81	51	0.01 - 0.08	0.03	0.05	0.06
Total Mercury	C	Mar 77 - Oct 81	53	<0.0005 - 0.0018	<0.0005	<0.0005	0.0005
Total Molybdenum	C	May 77 - Oct 81	51	ALL <0.03	<0.03	<0.03	<0.03
Total Nickel	C	Apr 78 - Jan 79	39	<0.05 - 0.19	<0.05	<0.05	0.05
Dissolved Nickel	C	Mar 77 - Oct 81	52	<0.05 - 0.10	<0.05	<0.05	<0.05
Total Selenium	C	Jan 78 - Oct 81	43	ALL <0.025	<0.025	<0.025	<0.025
Total Silver	C	Apr 77 - Oct 81	52	<0.02 - 0.03	<0.02	<0.02	0.02
Total Tin	C	May 77 - Oct 81	51	ALL <1.0	<1.0	<1.0	<1.0
Total Zinc	C	Mar 77 - Oct 81	53	0.04 - 0.72	0.05	0.10	0.15

(1) C - composite, G - grab
(2) All units are mg/L except where shown otherwise.

Prepared by GVS & DD.

TABLE 3: COMPARISON WITH CHARACTERISTICS OF MAJOR PACIFIC OCEAN OUTFALLS*

	Year Operation Began	Pipe Diameter (inside) (inches)	Length of Main Outfall (excl. diff.) (ft)	Length of Diffuser, L (ft)	Depth of Discharge (nominal) (ft)	Design Average Flow, Q (ft^3/sec)	Port Diameters[a] (inches)	Port Spacing (average)[b] (ft)	Velocity of Disch. (nominal) for av. Flow (fps)	Q/L (ft^2/sec)	Area Factor (total port area/ pipe area)
Sanitation Districts of Los Angeles County, White Point No. 3	1956	90	7,900	2,400	200-210	232	6.5-7.5	24	8	0.097	0.63
City of Los Angeles at Hyperion	1960	144	27,525	7,920	195	651	6.75-8.13	48	13	0.082	0.44
San Diego	1963	108	11,500	2,688	200-210	363	8.0-9.0[c]	48	15	0.135	0.39
Sanitation Districts of Los Angeles County, White Point No. 4	1965	120	7,440	4,440	165-190	341	2.0-3.6	6	9	0.077	0.51
Metro. Seattle (West Point)	1965	96	3,050	600	210-240	194	4.5-5.75	3	6	0.323	0.60
Sanitation Districts of Orange County, Calif.	1971	120	21,400	6,000	175-195	450	2.96-4.13	12	13	0.075	0.45
Honolulu (Sand Island)	1975	84	9,120	3,384	220-235	164	3.00-3.53	12	10	0.048	0.44
Iona (Vancouver)	-	2-80	23,200	3,525	200-320	163	4.0	10	5	0.046	0.45

a = Exclusive of end ports, which are usually somewhat larger.
b = Length of diffuser divided by number of ports; real spacings on each side of the pipe are twice the values indicated.
c = Blocked by orifice plates with openings of 6.5-7 in. for early years' low flow.
* = American references in table are from Reference 7.